Modeling of EM Waves for Seabed Logging Application using COMSOL

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Nur Sakinah Binti Yahaya)

ABSTRACT

Seabed Logging was introduced to the oil industry about ten years ago. It is a technique that utilizes Electromagnetic (EM) waves to propagate signals underneath seabed to determine the difference in resistivity levels in order to determine possible oil wells for exploration. This new technology would make it possible to identify the presence of oil and gas in undrilled prospects. Both research surveys and commercial investigations show that the technology functions as predicted. Therefore, the purpose of this project is to develop a 3D simulator that can model the sea bed environment and EM waves using COMSOL. This 3D simulator could show the EM waves in the form of direct waves, reflected waves and refracted waves for predefined seabed environment. This report describe briefly on the advantages of this technique as well as the process on how the EM wave is implemented to distinguish the hydrocarbon from other elements.

ACKNOWLEDGEMENTS

This final year project would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

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Last but not the least, I would like to thank my family: especially my parents Yahaya Mohd Yunus and Fatimah Kassim, for giving birth to me at the first place and supporting me spiritually throughout my life, my husband Kapten Dr. Amru Mohamad for being understanding and supporting throughout my studies, my family in-law for their encouraging advice, and the one above all of us Allah for answering my prayers and giving me the strength to complete my final year project.

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LIST OF ABBREVIATIONS

SBL	Seabed Logging
CSEM	Control Source Electromagnetic
EM	Electromagnetic
FYP	Final Year Project
E-field	Electric Field
HED	Horizontal Electric Dipole
PC	Personal Computer
PDE	Partial Differential Equation
GUI	Graphical User Interface

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hydrocarbon exploration is the research by petroleum geologists for hydrocarbon beneath the Earth's surface, such as oil and natural gas. Various techniques are used for this kind of exploration namely Seismic method and Control Source Electromagnetic (CSEM) [7]

Seismic methods are widely accepted and considered as proven technology for hydrocarbon exploration and reservoir characterization [1]. However, seismic method can identify structures that might be expected to contain hydrocarbons, but it is practically blind to the fluids contained in the formation [2]. This explains why geophysicts' are now prefer CSEM technique for Seabed logging which is more accurate and detail in giving the result before drilling. Seabed logging is the measurement of electrical resistivity beneath the seafloor that has played a crucial role in hydrocarbon exploration and reservoir assessment and development [3]. This technique is expensive and due to this it is used to complement seismic method.

Clear advantage has been seen as to provide the necessary information without resolving to invasive geophysical methods. This method has the ability to distinguish between hydrocarbon and water [4].

1.2 Problem Statement

The problem statements of this project are:

i. Data receive from the receivers consist of many values. Hence, user needs a device to translate the data into meaningful figure which is much easier to be understood and interpreted.
ii. Predicting the location of hydrocarbon underneath the sea floor is very challenging. Thus, modeling of SBL under control environment using suitable Electromagnetic (EM) modeling technique to differentiate between water, sediment, and hydrocarbon layer plane are needed.
iii. In shallow water, the ocean bottom receivers also measure a strong refraction and reflection off the sea surface, jointly referred to as the airwave. Therefore, it is important to consider the effect of airwave to the receiver when the depth of seawater is less than 1000m.

1.3 Objectives

The objectives of this project are:

i. To create 3D seabed logging simulator using COMSOL software and to create Graphical User Interface.
ii. To construct an Electromagnetic (EM) forward model or plane layer modeling that has air, seawater, sediment, and hydrocarbon layer plane according to their resistivity values.
iii. To determine the effect of airwave to the EM data when parameters such as sea depth, water level, and frequency are varied.

1.4 Scope of Study

In order to complete this project, several scope of study had to achieve. The major scopes are as follows:

1.4.1 Understanding Seabed Logging method.

- The Research towards the processes involved in seabed logging technique and the existing issues related to it.
- Research on measurement principle of Seabed Logging to excite the EM waves in a hydrocarbon reservoir.
- The proper ways of handling and processing the data are to be considered.

1.4.2 Developing Seabed logging simulator using COMSOL

- There will be a need to install COMSOL software into personal computer (PC).
- The proper ways of handling the software should be considered. For example; all latest Windows' version can use this software except Window Vista and at least 2 GB of RAM-Disc, 160 GB of Disc Memory, and 64bits type of PC are required.
- Training on how to use COMSOL software in order to develop the simulator.
- The knowledge on electromagnetic (EM) principle and tools offered in the software will help to achieve the project objective.
- The simulator shall then be used to model the Electromagnetic waves to detect potential hydrocarbon when different parameters are varied.

1.5 Feasibility of Project

Two semesters will be required to complete this project. For the first semester, author will start the project with research on electromagnetic waves and its application as well as the development of the simulator using COMSOL. Learning the software is an important aspect in Final Year Project (FYP) 1 to prepare for better results in FYP2

The second semester will focus on the simulation and data collection of the modeling in Electromagnetic wave. All the data will then be interpreted for technical report.

With the resources that are available in the University, the project shall be completed within the given time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

One of the important breakthroughs in marine geophysics is the development of new technique for the remote and direct identification of hydrocarbon reservoirs underneath seafloor based on EM measurement. SBL method is an improvement from Seismic reflection method for better precision in hydrocarbon detection.

2.2 Seismic

A seismic survey uses acoustic waves is an indirect method of exploring geological structures deep underneath seabed in the search for oil and gas accumulations. Computers are used to identify different rock layers and structures by calculating the intensity of the reflected sound waves and the time it takes for them to travel through the rocks and back to the surface. The data is used to create two or three-dimensional images of the layers and the location of these structures. Seismic methods have changed over the years to reduce surface disturbance and many surveys are now using 'low impact seismic' which utilize minimal cut lines and heliportable devices [5].

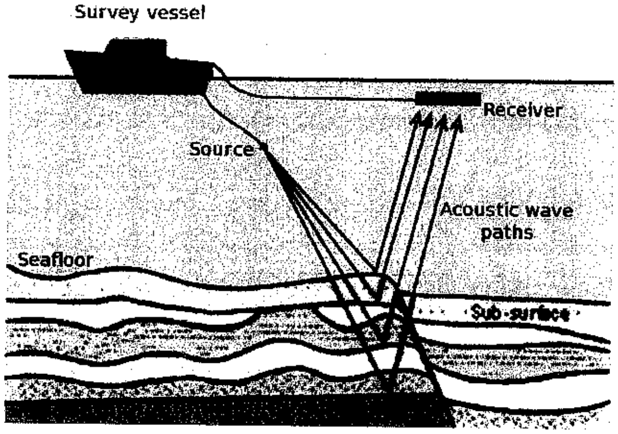

Figure 1: Illustration of seismic reflection profiling

However, the seismic surveying can identify structures that might be expected to contain hydrocarbons, it has the drawback that it is practically blind to the fluids contained in the formation. This explains why roughly three out of four prospects highlighted by traditional means turn out to be dry. On the other hand, seabed logging method will respond to the fluids in the rock, to confirm the prospects identified by seismic surveying [2].

2.3 CSEM

Controlled-source electromagnetic (CSEM) method is a measurement of electrical resistivity to distinguish between hydrocarbon and saline reservoirs because hydrocarbon reservoirs are usually one to three orders of magnitude more electrically resistive than saline reservoirs [3]. The reason is that water supports free ions and easily transports electric current where hydrocarbon acts as insulator [4]. With an in-line antenna configuration, the transmitted electromagnetic waves enter the high resistive hydrocarbon layer under a critical angle and are guided along the layer.

The signal from antenna constantly leak from the layer and back to the receiver at the seafloor. The guiding of the electric fields significantly alters the overall pattern of current flow in the overburden layer. The resistivity difference is mapped as a function of depth by measuring the electric and magnetic fields at the seafloor from an electric dipole source as a function of the transmitter-receiver. Resistive layers appear as an increase in electric field [5]

Thus, by using controlled source electromagnetic (CSEM) methods it can effectively differentiate between different types of offshore reservoir fluids. This method measures electromagnetic fields with sensors on the ocean floor. A deep-towed transmitting antenna then generates low-frequency electromagnetic fields, which are detected by the sensors. Both antenna tow lines and sensor arrays can cover areas ranging to thousands of square kilometers [6].

2.4 Seabed Logging

Seabed Logging (SBL) is an application of the marine controlled source electromagnetic (CSEM) method that is used to directly detect and characterize possible hydrocarbon-bearing prospects. Although the CSEM method has been used by academia for more than three decades, the application as a direct hydrocarbon indicator was first introduced about ten years ago [7].

The seabed logging (SBL) is a resistivity-based tool for directly detecting the presence of oil and gas reservoirs in exploration prospects prior to drilling [8]. It is a fact that the hydrocarbons and hydrocarbon reservoirs have higher resistivity than surrounding water filled sediments. The changes in electric field around the reservoirs can be measured, and the data gained can be used to interpret the presence of hydrocarbon.

The first SBL survey was first performed at offshore Angola. The survey was a result of successful laboratory testing and since then, the interest in electromagnetic methods for subsurface exploration has increased [8].

Today, electromagnetic methods are attractive for the petroleum industry as complementary tools to seismic methods, or even standalone tools, for remote sensing of the subsurface. The method relies on large resistivity contrast between hydrocarbon saturated reservoirs, and the surrounding sedimentary layers saturated with aqueous saline fluids [1].

Horizontal Electric Dipole (HED) source is used to emit low frequency electromagnetic signal that will be received by an array of seafloor receivers. The electromagnetic energy from the source spread in all direction and rapidly attenuated in the conductive subsurface sediments due to water-filled pores. The rate of decay in the amplitude and the phase shift of the signal are controlled by geometric and skin depth effects.

SBL method has been a wide interest in hydrocarbon exploration since a number of success stories on applications of this have been published [8 and 7]. A latest publication [4] evaluates statistical results from wells drilled on prospects or fields containing CSEM data and shows bright future in its application for hydrocarbon exploration.

From 86 wells with associated CSEM data, 36 are calibration surveys collected to test the technology and 50 are exploration well drilled after the acquisition of CSEM data. Of the 22 calibration surveys acquires over existing discoveries, 19 (86%) show a significant CSEM anomaly (potential existence of hydrocarbon reservoir). Of the 14 calibration, surveys acquired over prospects that are proven dry, 13 (93%) show no significant CSEM anomaly [5].

When disregarding all calibration surveys, 28 out of 50 wells are discoveries. When considering wells drilled on prospects with a significant CSEM anomaly, 21 out of 30 exploration wells are discoveries. For exploration wells drilled on prospects without a significant CSEM anomaly, 7 out of 20 wells are drilled

This provides an overall success rate (in terms of technical success regardless of commerciality) of 56%. For wells drilled on prospects with a significant CSEM anomaly, the success rate increases to 70%, whereas it drops to 35% for wells drilled on prospects without a significant CSEM anomaly. As such, the average success rate for wells drilled on prospects with a significant CSEM anomaly is twice the average success rate for wells drilled on prospects without a significant CSEM anomaly.

From exploration point of view, this is important as the technology provides means for the oil companies in finding commercial volumes of hydrocarbons prior to drilling. With the documented success of the technology from empirical data, there should be little doubt about the potential of the technology in oil industry.

2.5 Theory

This section discussion on the basic theories involve in conducting data processing in SBL.

2.5.1 Wave Propagation Paths in a Hydrocarbon Reservoir

In high resistance layers such as hydrocarbon, skin depth in the seabed are longer and at a critical angle of incidence, energy is guided along the layers and attenuated to a lesser extent. Energy refracted back to the seabed and detected by electromagnetic receivers positioned thereupon [9]

The receiving data is processed and presented in two dimensional model to map a hydrocarbon reservoir. Figure 2 shows five components of received EM waves which are:

I. Direct waves – EM waves from transmitter.
II. Air waves – EM waves reflected back at the boundary of air and seawater.
III. Reflected waves – EM waves from seabed or host rock.
IV. Reflected waves – EM waves from hydrocarbon.
V. Guided waves – EM waves through hydrocarbon.

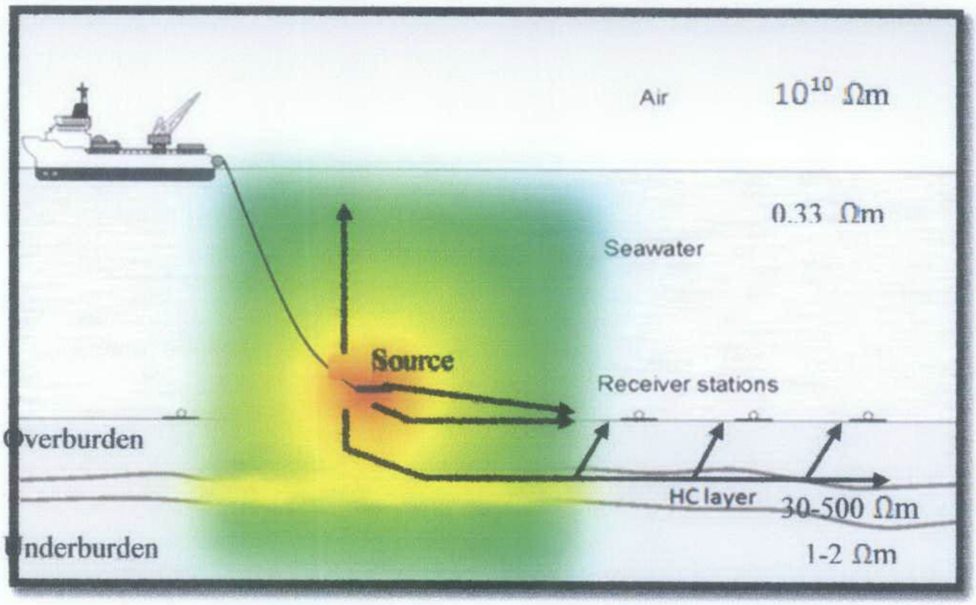

Figure 2: Seabed logging process

As illustrated in figure 2, seabed receivers record the EM responses as a combination of energy pathways including signal transmission directly through seawater, reflection and refraction via the seawater-air interface, refraction and reflection along the seabed, and reflection and refraction via possible high resistivity subsurface layers.

Low frequency EM waves decay exponentially with distance z (m) by $e^{-z/\delta}$ where:

$$\delta = \sqrt{\frac{2\rho}{(8 \times 10^{-7})(\pi^2)(f)}} \qquad (1)$$

Where

ρ = resistivity (Ωm)

f = signal frequency (Hz)

The distance required to attenuate an EM signal by the factor $e^{-1}(0.37)$ is defined as the skin depth and is about 551 m in seawater (0.3 Ωm), 1424 m in 2 Ωm sediment and 108 m in air (10^{10}Ωm) for a 0.25 Hz signal. EM signals are rapidly attenuated in seawater and seafloor sediments saturated with saline water, and these signal pathways will dominate at near source-to-receiver offsets (~ 3 km) [8]

In high resistivity and relatively thin (20-200 m) subsurface media, such as hydrocarbon filled reservoirs (30-500 Ωm), the energy is guided along the layers and attenuated less depending on the critical angle of incidence [11]. Guided EM energy is constantly refracted back to the seafloor and is recorded by the EM receivers. Energy is also reflected and refracted via the air-water interface. This energy is commonly termed the air-waves and dominates at far offsets (~ 6 km) depending on water depth.

The refracted energy from high resistivity subsurface layers will dominate over directly transmitted energy when the source-receiver distance is large enough (approximate 3 times the target depth) [4 and 8]. The detection of this guided and refracted energy from hydrocarbon is the basis SBL.

However, when moving to shallow water depths this is no longer the case as the airwave will mask the subsurface responses. Shallow water column provides less conductive material to diffuse through compared to deep water column, the airwave is less attenuated in former case than the latter [3].

The airwave component will diffuse in the downward direction and be almost normal incident to seabed, whereas the guided modes (Reflected Wave from Hydrocarbon and Guided Wave from Hydrocarbon) associated with hydrocarbon will leak out and diffuse in the upward direction [4].

2.5.2 Electromagnetic Waves

In electromagnetic waves most of the theory is related to Maxwell's equations and it is stated that magnetic field produced (B) is proportionally related to the current and the type of material used. The bigger the current flows inside a conductor and the higher the permeability of the material used, then the bigger the B field is produced [9].

Both magnetic field (B) and electric field (E) are propagating perpendicularly to each other with the same amplitude where the reduction in B field intensity will cause the same amount of reduction in E field as well [9].

Based on Maxwell equation [9]:

$$B = \frac{\mu_0 I}{2\pi r} \tag{2}$$

Where;

B = Magnetic field,

$\mu 0$ = Permeability

I = Current

r= Distance

2.5.3 Skin Depth

The decay of electromagnetic fields in a medium is governed by both the resistivity of the medium and the frequency of the signal [7]. The electromagnetic skin depth defines the distance over which the amplitude of an electromagnetic field decays by a factor 1/e and the phase of the signal is shifted by radians [6]:

$$\delta = \sqrt{\frac{2}{\mu\sigma\omega}} \approx 500\, meters \times \sqrt{\frac{\rho}{f}} \qquad (3)$$

Where,

δ = The skin depth in meter.

σ = The conductivity of the propagation medium.

μ = The permeability of the propagation medium.

$\omega = 2\pi f\ (rad/s)$ The angular frequency of the wave.

ρ = Resistivity of medium which the electromagnetic field is diffusing.

f = Frequency of the wave.

The frequency at which signals are transmitted must be carefully chosen, taking into account the possible resistivity and scale of structures which might be encountered. If the frequency is too low, the skin depth in the seafloor is very long so the signal is not inductively attenuated between the source and the receiver and cannot resolve crustal scale structure [7]. If the transmission frequency is too high, the skin depth is very small and signals only penetrate the shallow part of the crust. All but the very shortest range signals are attenuated to such an extent that they can no longer be detected above the noise [8].

Another consideration is the noise spectrum. At frequencies below approximately 0.3 Hz, microseism noise is significant and at lower frequencies still, ionospheric noise starts to leak through the conductive ocean. The range of frequencies which can be usefully employed for probing crustal structure to depths of a few kilometers or more is therefore between a few tenths and a few tens of Hertz.

2.5.4 COMSOL Software

COMSOL is a powerful interactive environment for modeling and solving all kinds of scientific and engineering problems based on partial differential equations (PDEs). *This software will be the main tool for developing the simulation of the* electromagnetic waves in seabed logging applications. With this software author can easily extend conventional models of one type of physics into multiphysics models that solve coupled physics phenomena and do so simultaneously. COMSOL can internally compile a set of PDEs representing the entire model. This software also is a standalone product through a flexible graphical user interface, or by script programming in the MATLAB language.

Figure 3: COMSOL Multiphysic software

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

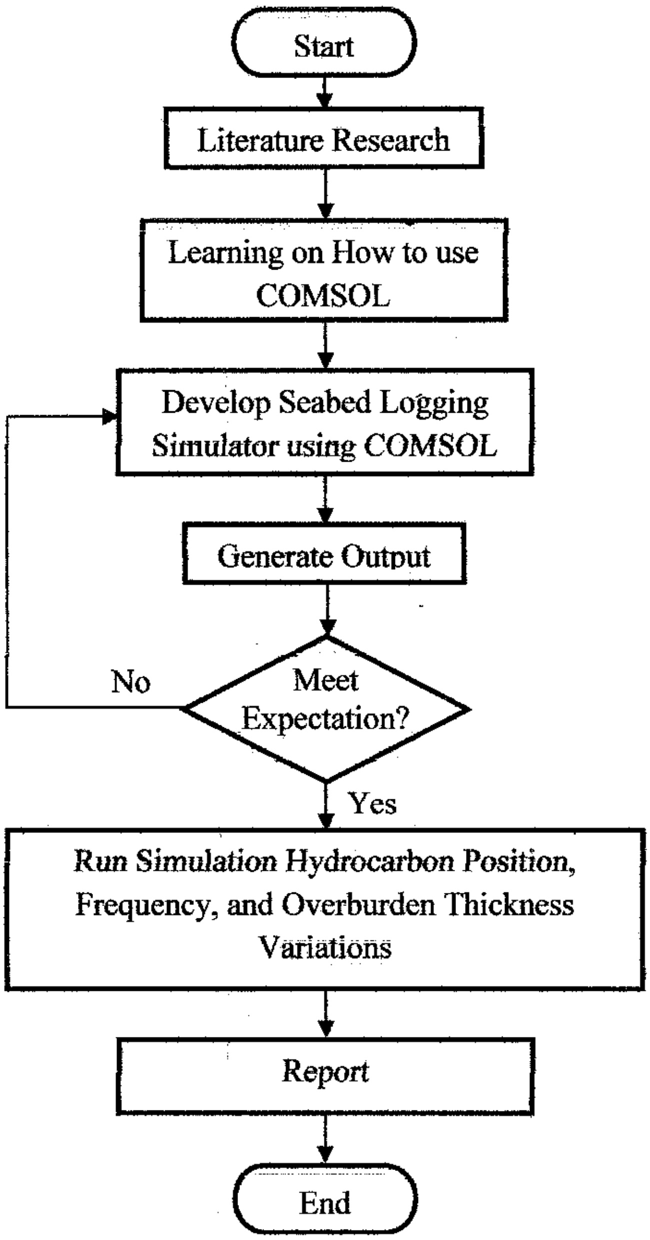

Figure 4: Flow Diagram of the Project

3.2 Work Scope

3.2.1 Data Gathering and Research

Data gathering and research to acquire the theoretical equations for model development is done via articles, journals and papers regarding SBL and EM wave to ensure the accuracy of collected data.

3.2.2 Developing SBL Simulator

Seabed Logging 3D Simulator was developed using COMSOL software based on forward modeling technique. The simulator was developed under ideal or equilibrium situation which was not considering noise, seawater density, temperature and others. Each component of received signals was processed as part of data representation in three-dimensional view. Finally, the working model was verified by conducting experiment regarding the study requirements that were affecting on changing the source frequency and variation of hydrocarbon reservoir thickness.

3.2.3 Parameters Variation

Changing parameters in SBL can affect hydrocarbon detection and mapping. Parameters that have been varied were:

1. The location of the hydrocarbons.
2. Frequency of the transmitter.
3. Overburden thickness.

Received waves components were observed and analyzed to be used for future study.

3.3 Tool and Equipment Required

3.3.1 COMSOL 3.5a

As stated in Section 2.4.5, SBL Simulator was developed using Comsol software. RF module was used as a medium for this simulator because it provides a unique environment for the simulation of electromagnetic waves in three dimension modeling. Figure 5shows Comsol's model navigator used to select the application module to be used which is the RF module.

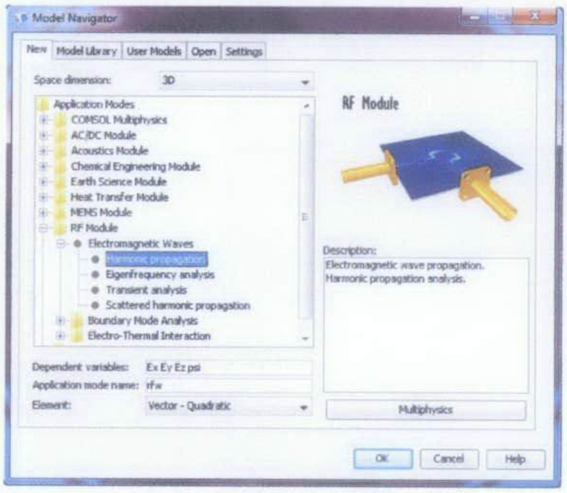

Figure 5: Model Navigator

The environment used for this simulator was based on data gathered from research of a real seabed logging environment. Comsol Multiphysics also provide user with GUI which help user to easily create a model by using all the tools given. Figure 6 show Comsol Multiphysics GUI to develop the SBL model.

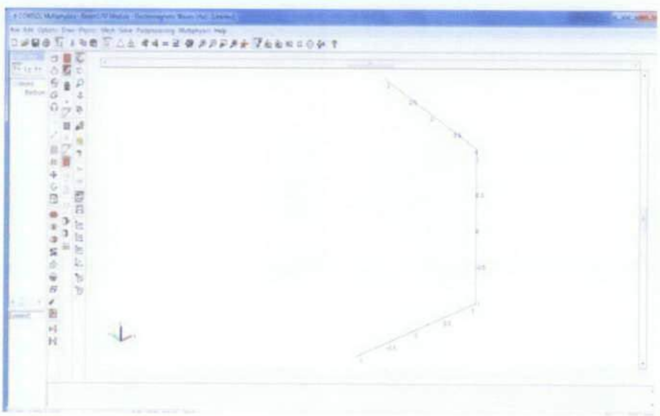

Figure 6: COMSOL Graphical User Interface (GUI)

3.4 Developing SBL Simulator

SBL simulator was developed to generate plane layer model and EM field of the waves received by the receivers based on ideal environment. Users are able to key in desired parameters through the simulator.

When creating a model in Comsol Multiphysics, the typical modeling steps include:

I. Creating the geometry
II. Defining the physics on the domains
III. *Meshing the geometry*
IV. Solving the model
V. Postprocessing the solution
VI. Performing parametric studies

Before started with all the steps user need to complete some setting by click on COMSOL Multiphysic 3.5a and Comsol's model navigator will appear as in figure 5 and then Select New at the tab menu. From the tab select 3D for the space dimension, select Harmonic Propagation, and then click OK.

3.4.1 Geometry Modeling

"Block" tool was use to create block for air, seawater, sediment and hydrocarbon. This tool allow user to set the length and axis base point of the block as illustrated in figure 7 and then click "Ok" the block will appear .

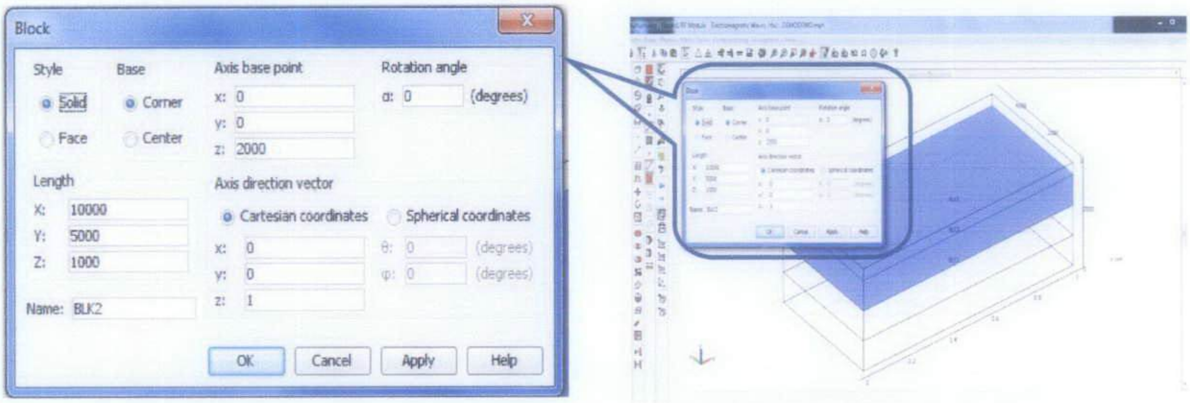

Figure 7: Creating block for air, seawater, sediment, and hydrocarbon layer by using Block tool

"Line" tool was use to create the transmitter and also receiver of the seabed logging environment. This tool allow user to set the coordinate of the line as illustrated in figure 8 and then click "Ok" the block will appear.

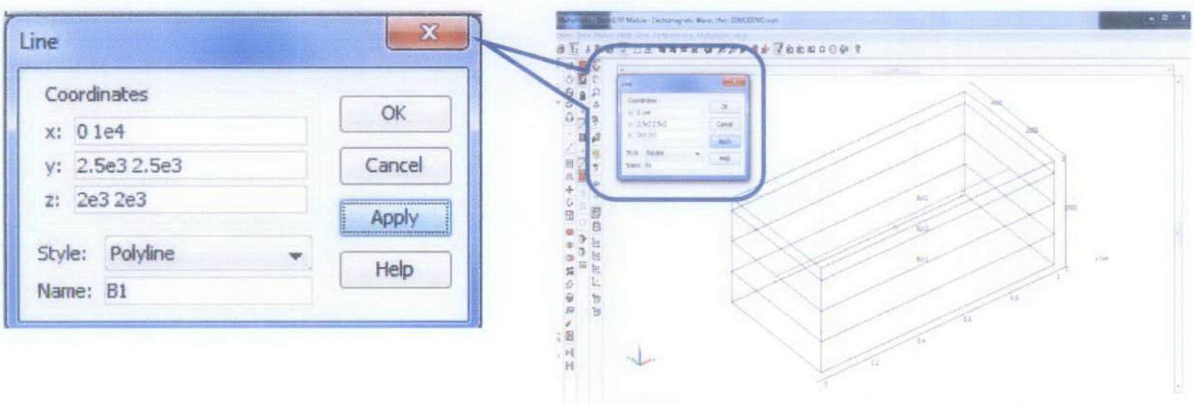

Figure 8: Creating Transmitter and receiver by using Line tool

3.4.2 Physic Setting

User can find the "Physic" menu at the menu bar with the same row as File, Edit, Plot Processing and Mesh. In physic menu there are four setting that need to be set which are:

I. Subdomain setting
II. Boundaries setting
III. Edge setting
IV. Scalar variable setting.

"Subdomain" setting as being illustrate in figure 9 is to set the material properties and for the seabed logging application. User need to set up the relative permittivity and electric conductivity of the seabed environment. Table 1 shows the setting parameter for this environment.

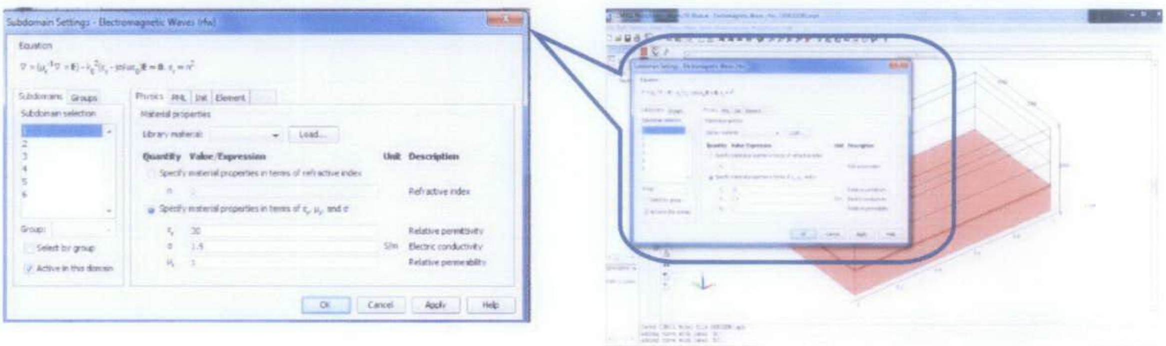

Figure 9: Subdomain setting

Setting	1	2	3	4	5	6
Relative permittivity	30	4	4	30	80	1
Electric conductivity	1.5	0.001	0.001	1.5	3	0.001

Table 1: Subdomain setting parameters for model with hydrocarbon

"Boundaries" setting as being illustrate in figure 10 is to set the different dielectric regions in the rectangular waveguides. From boundaries tab select the region by group and click on the boundary selection list. At condition tab select scattering boundaries condition and spherical wave type.

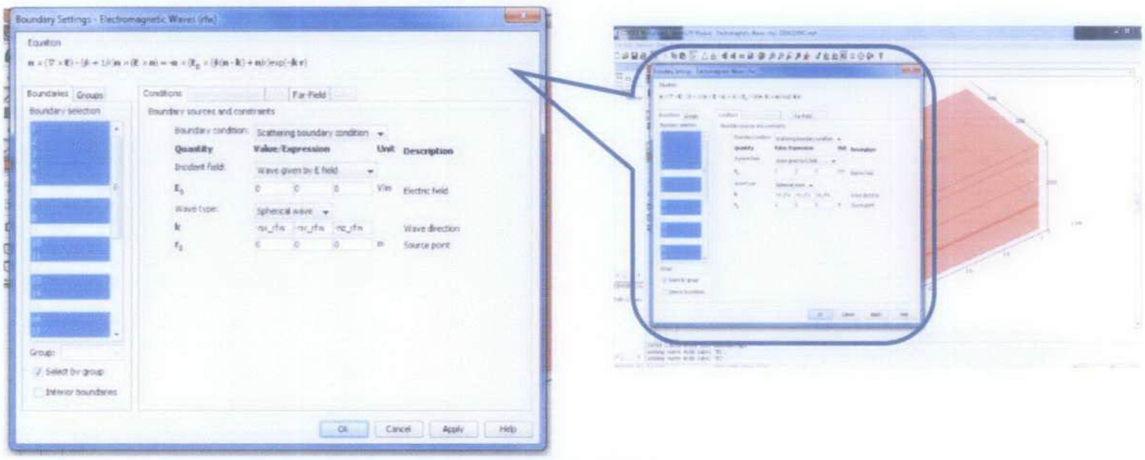

Figure 10: Boundaries setting

"Edge" setting as being illustrate in figure 11 is to describe the physics on a model's main domain and work similar way as the point settings. On edge selection, select point that being assign to be the transmitter point. Than at coefficients tab, select current in edge segment direction and key in the value for the transmitter current. Based on research, transmitter current used for seabed logging are 1250 A.

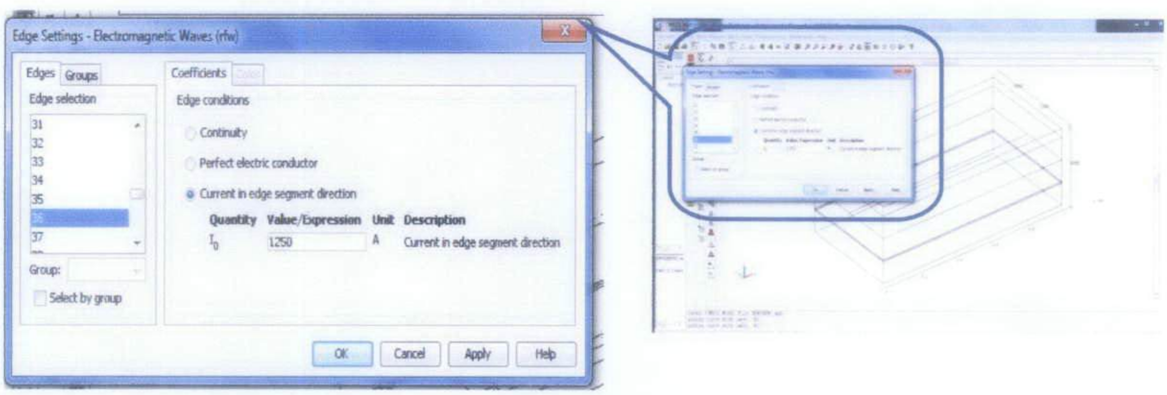

Figure 11: Edge setting

"Application Scalar Variable" setting as being illustrate in figure 12. The values of each scalar variable can be changed by making an entry in the edit field in the Expression column. Hence, for this seabed model user need to change the Expression of frequency description only.

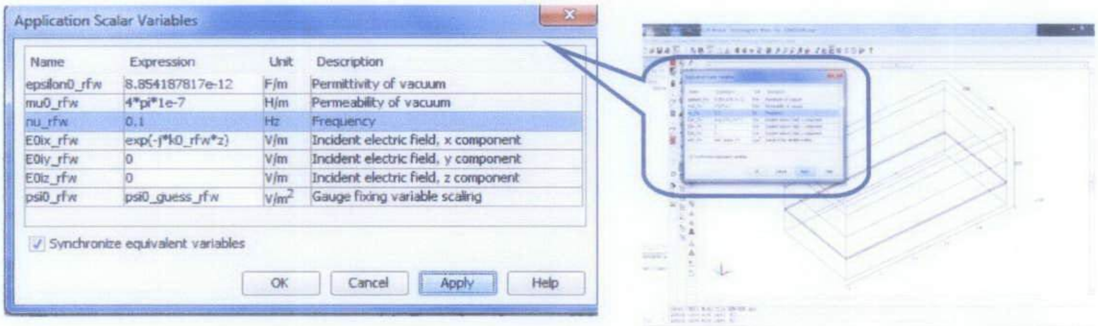

Figure 12: Application scalar variable setting

3.4.3 Meshing Geometry

User can find the "Mesh" menu at the menu bar with the same row as File, Edit, Plot Processing and Physic as being illustrated in figure 13. Inside the mesh menu user need to set for the Free Mesh Parameters only.

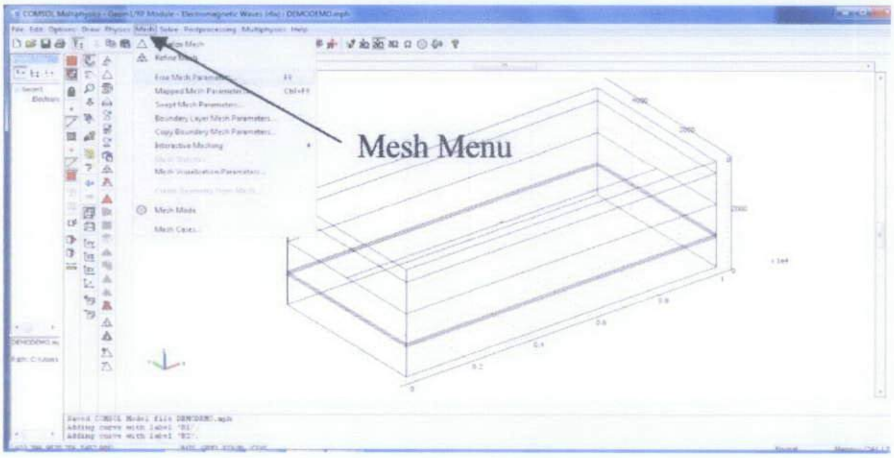

Figure 13: Mesh Menu

"Free Mesh Parameters" setting as being illustrate in figure 14 is being set up. From Global tab select the custom mesh size and set the maximum element size. For this model the maximum element size is set to be 1e3.

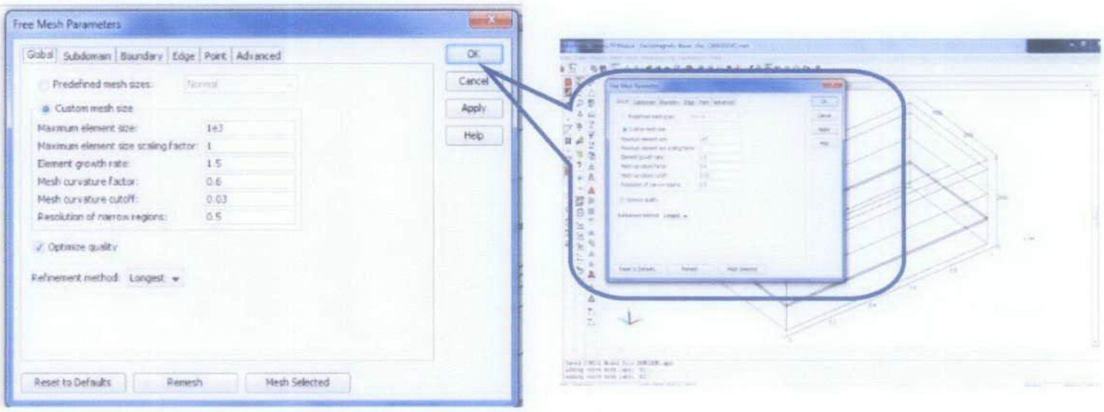

Figure 14: Free mesh parameter setting

Creating a free mesh containing tetrahedral elements, or a swept mesh containing prism elements or hexahedral elements can be chosen. a 3D mesh can be created by extruding 2D mesh. When a 2D mesh are extruded into 3D mesh, triangular element and quadrilateral elements in the 2D mesh are extruded into prism (wedge) elements and hexahedral (brick) element, respectively, as illustrated in figure 15. After meshing user need solve it by clicking on the solve icon " = ".

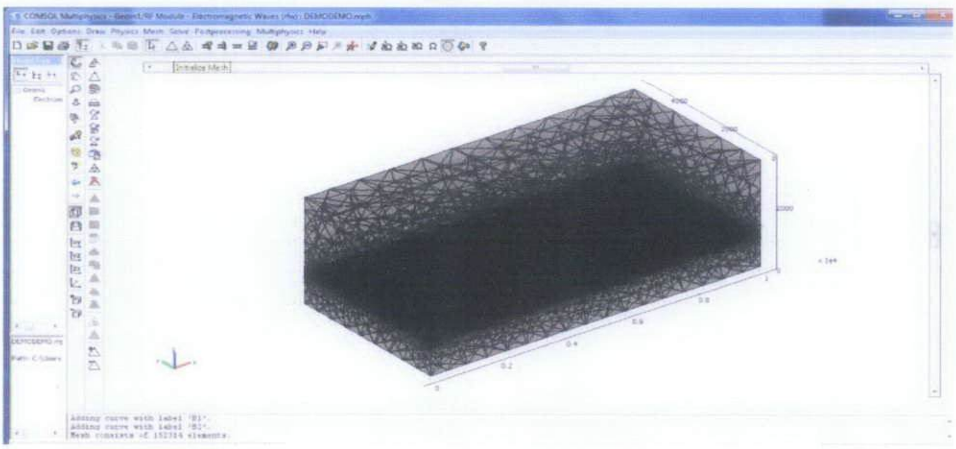

Figure 15: Mesh Model

3.4.4 Post Processing the Model

User can find the "Post Processing" menu at the menu bar with the same row as File, Edit, Mesh and Physic as being illustrated in figure 16.

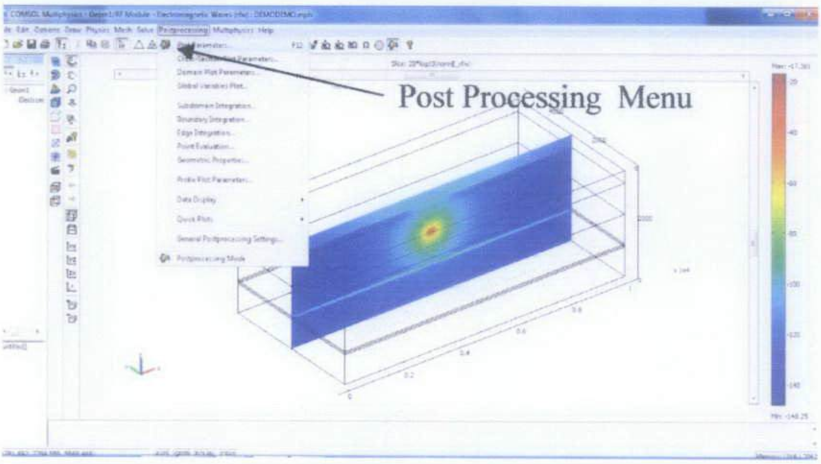

Figure 16: Post Processing Menu

"Boundaries" setting as being illustrate in figure 17 is to Plot parameters is to get visualizations on the solution domain using the common plot types. From plot parameter select on the slice tab and key in 20*log10(norm_rfw) in the expression. Number of levels for x=0, y=1, and z=0. The slice plot is default type and it displays a quantity as a set of colored slices through geometry.

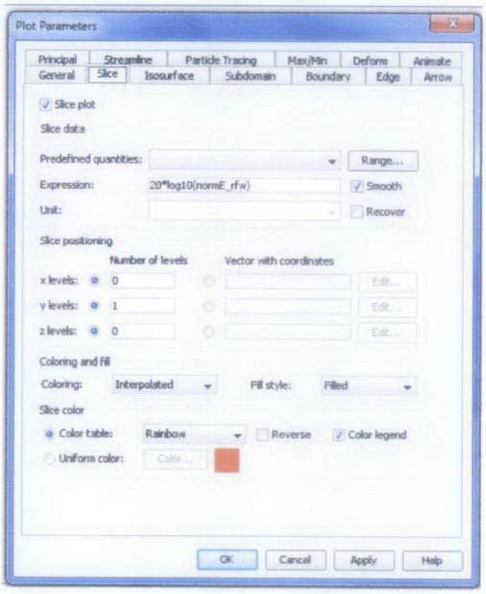

Figure 17: Plot Parameter setting

"Domain Plot Parameters" setting as being illustrate in figure 18 is to visualize on one or several surfaces as a quantity in time or along a parameter range. On surface tab key in 20*log10(norm_rfw) in the expression and select the boundary to plot in the boundary selection list. Boundary to be plot is the receiver boundary which is boundary 22.

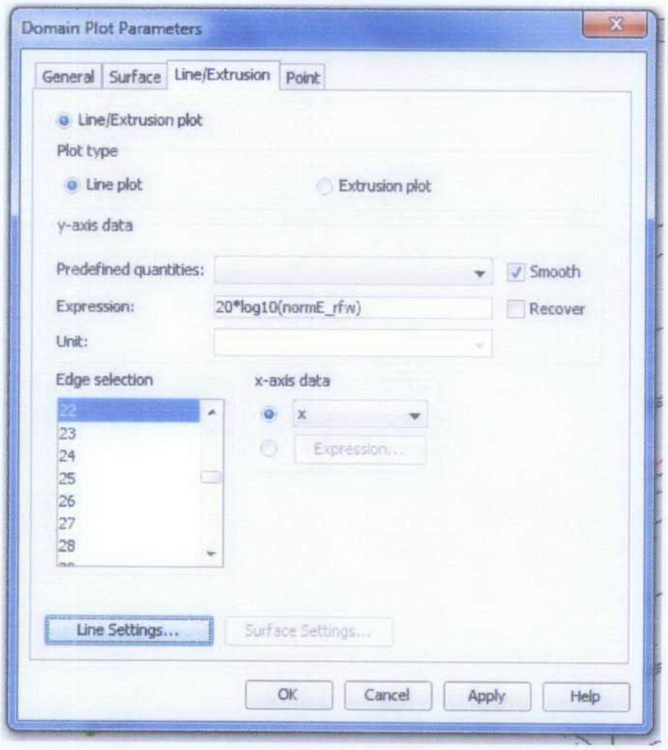

Figure 18: Domain Plot Parameter Setting

Figure 19 shows result of the domain plot parameter for model with hydrocarbon.

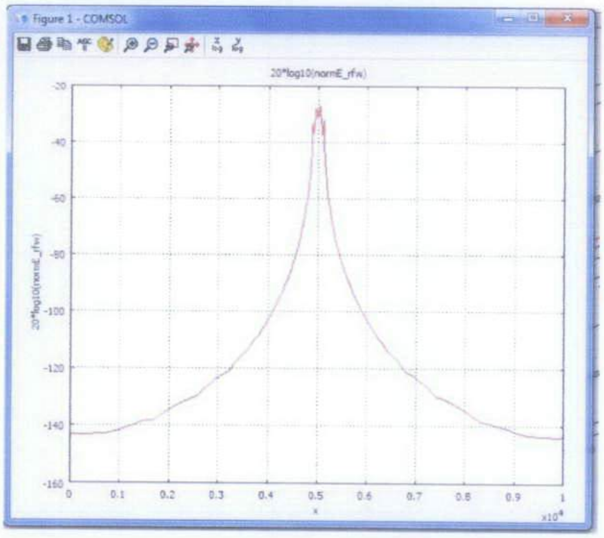

Figure 19: Result of Domain Plot Parameter for model with hydrocarbon

3.4.5 Simulator Without Hydrocarbon

For simulator model without hydrocarbon user need to repeat procedure from the "Physic Subdomain" setting as being illustrate in figure 20.The material properties for this model need to be set up again as in the table 2 that shows the setting parameter. Then user need to mesh the model again and solve it by click on the mesh and solve symbol.

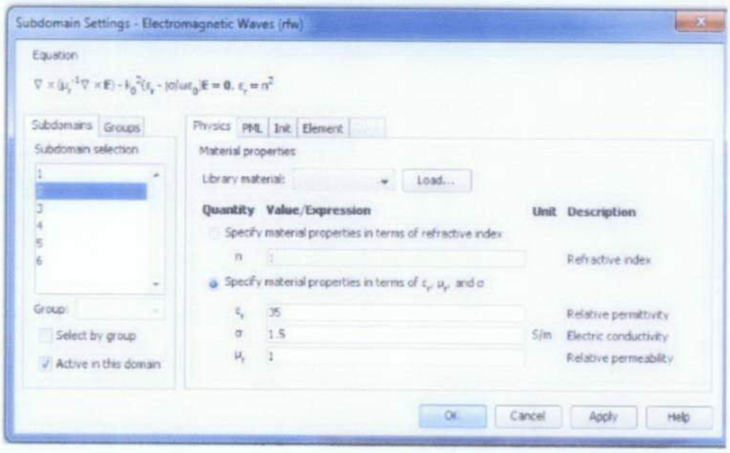

Figure 20: Subdomain Setting for model without hydrocarbon

Setting	1	2	3	4	5	6
Relative permittivity	30	30	30	30	80	1
Electric conductivity	1.5	1.5	1.5	1.5	3	0.001

Figure 2: Subdomain setting parameters for model without hydrocarbon

In post processing menu select the "Domain Plot Parameter" and as in figure 21 at Line/Extrusion tab select the boundary to plot which is boundary number 22. Change the line color from the "Line Setting" and at General tab tick on the "keep current plot" as shown in figure 22.

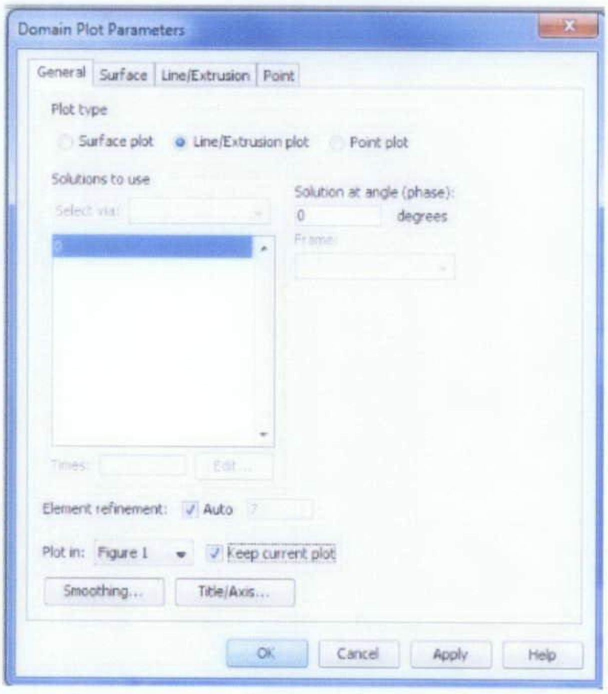

Figure 21: Domain Plot Parameters Setting for model without hydrocarbon

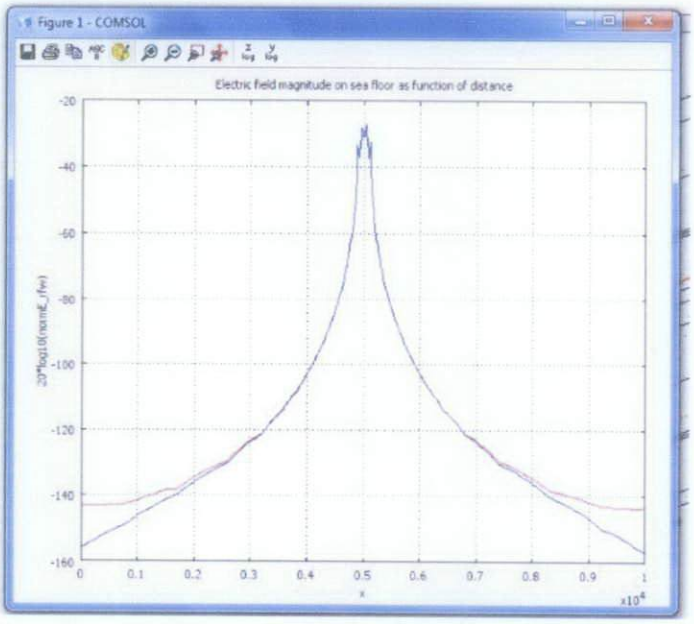

Figure 22: Result for model with and without hydrocarbon

3.4.6 Seabed Logging Model

Figure 23 show the seabed logging model that had been developed using Comsol and specification for each layer. As stated in Section 3.4.2, subdomain setting is to set the material properties and for the seabed logging application. Hence, in table 3 and 4 shows the material property for air, seawater, sediment, and hydrocarbon.

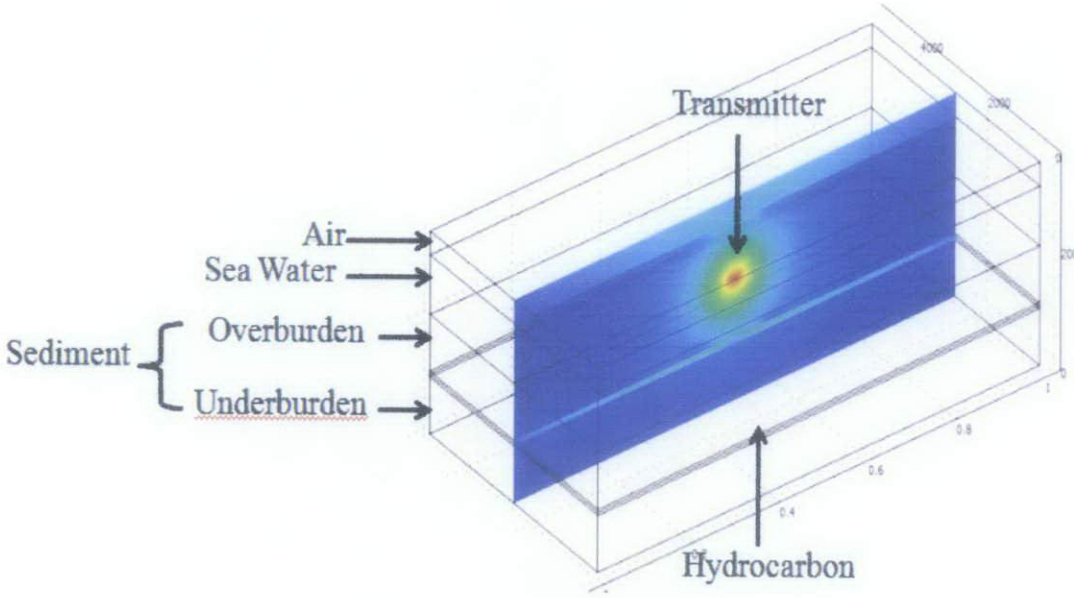

Figure 23: Seabed Logging 3D Model using COMSOL Multiphysic

Setting	Sea water	Hydrocarbon	Air	Sediment
Relative Permittivity	80	4	1	30
Electric Conductivity	3	0.001	0.001	1.5

Table 3: parameter setting for the seabed logging with hydrocarbon

Setting	Sea water	Hydrocarbon	Air	Sediment
Relative Permittivity	80	30	1	30
Electric Conductivity	3	1.5	0.001	1.5

Table 4: parameter setting for the seabed logging without hydrocarbon

3.5 Parameter Variations

Some models have been developed by using COMSOL that reflect the seabed logging 3D simulation. However, the simulator has been modified to observe the differences on the results by changing the following parameters:

3.5.1 Hydrocarbon Position

In hydrocarbon variation, the model had been modified while other parameters are fix. Hydrocarbon size had been change to a smaller size and the position was varied as below:

I. Hydrocarbon is at coordinate: x= 8000, y= 2500, z= 1250
II. Hydrocarbon is at coordinate: x= 2000, y= 2500, z= 1250
III. Hydrocarbon is at coordinate: x= 13150, y= 2500, z= 1250

3.5.2 Frequency of the transmitter

For frequency variation, the model and other parameters are fix accept frequency of the transmitter. The frequency of the transmitter is varied as below:

I. 0.1 Hz
II. 0.25 Hz
III. 0.5 Hz
IV. 0.75 Hz
V. 1.0 Hz

3.5.3 Overburden Thickness

For overburden thickness, the model had been modified while other parameters are fix accept. The overburden thickness is varied as stated below:

I. 1000 m
II. 1500 m
III. 2000 m
IV. 2500 m
V. 3000 m
VI. 3500 m
VII. 4000 m

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Varying the Hydrocarbon Position

4.1.1 Hydrocarbon is at coordinate: x= 8000, y= 2500, z= 1250

As stated in 3.5.1, following are the results obtained after varying the hydrocarbon position. As in figure 24 the hydrocarbon was in a shape of a rectangular box and it is located under transmitter which could be seen in the middle of the SBL model.

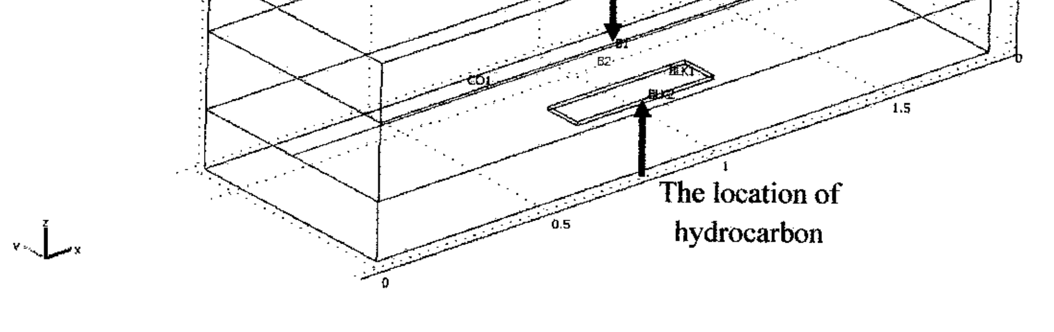

Figure 24: Location of hydrocarbon

After creating and assigning parameter in geometry for the SBL environment, meshing had been done on the geometry to get the number of mesh elements. From figure 25, it shows the SBL model with hydrocarbon and area that has large number of mesh element is where the hydrocarbon was located,

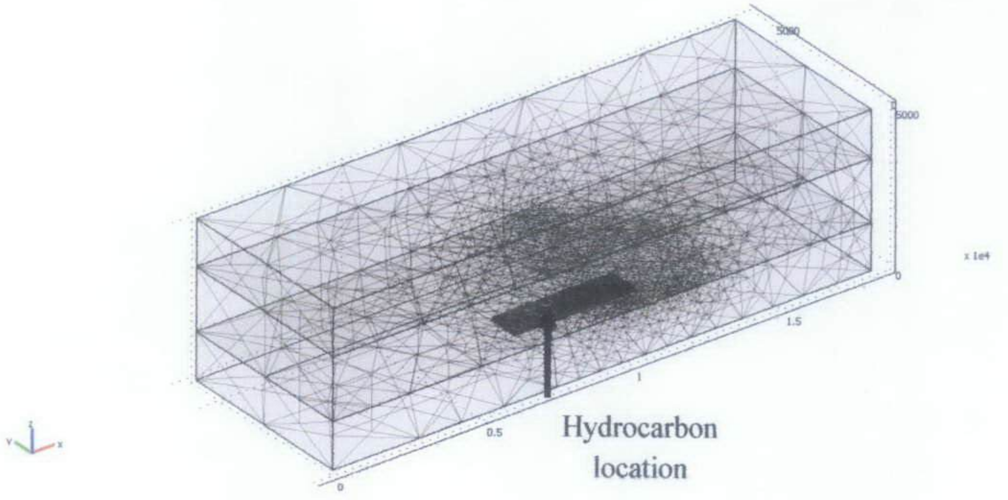

Figure 25: Mesh geometry of the seabed logging

Figure 26 shows the guiding effect of the hydrocarbon layer where as red color in the middle of the model shows the area that have the highest total energy density.

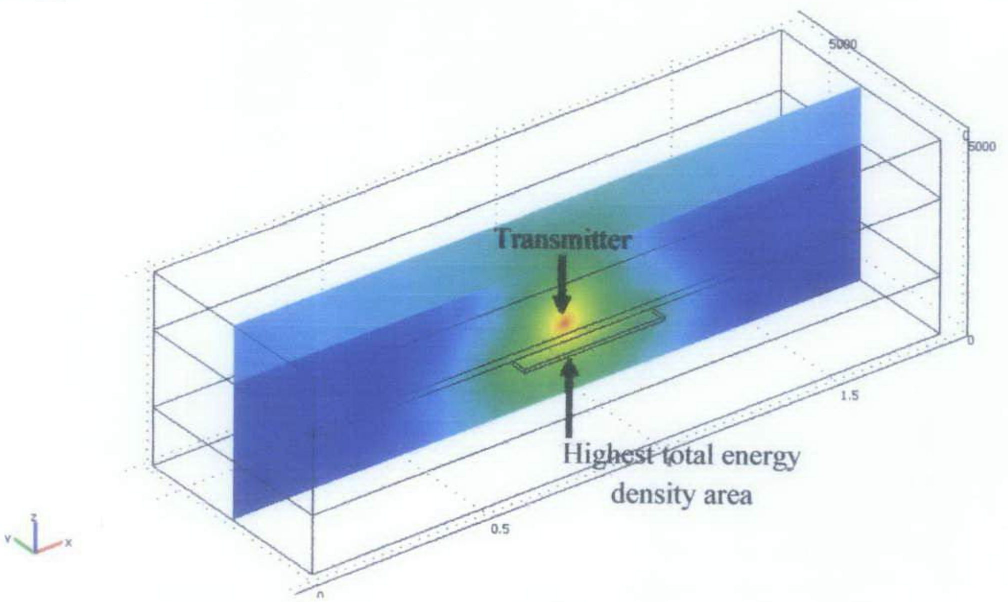

Figure 26: Total energy density on linear scale

Result:

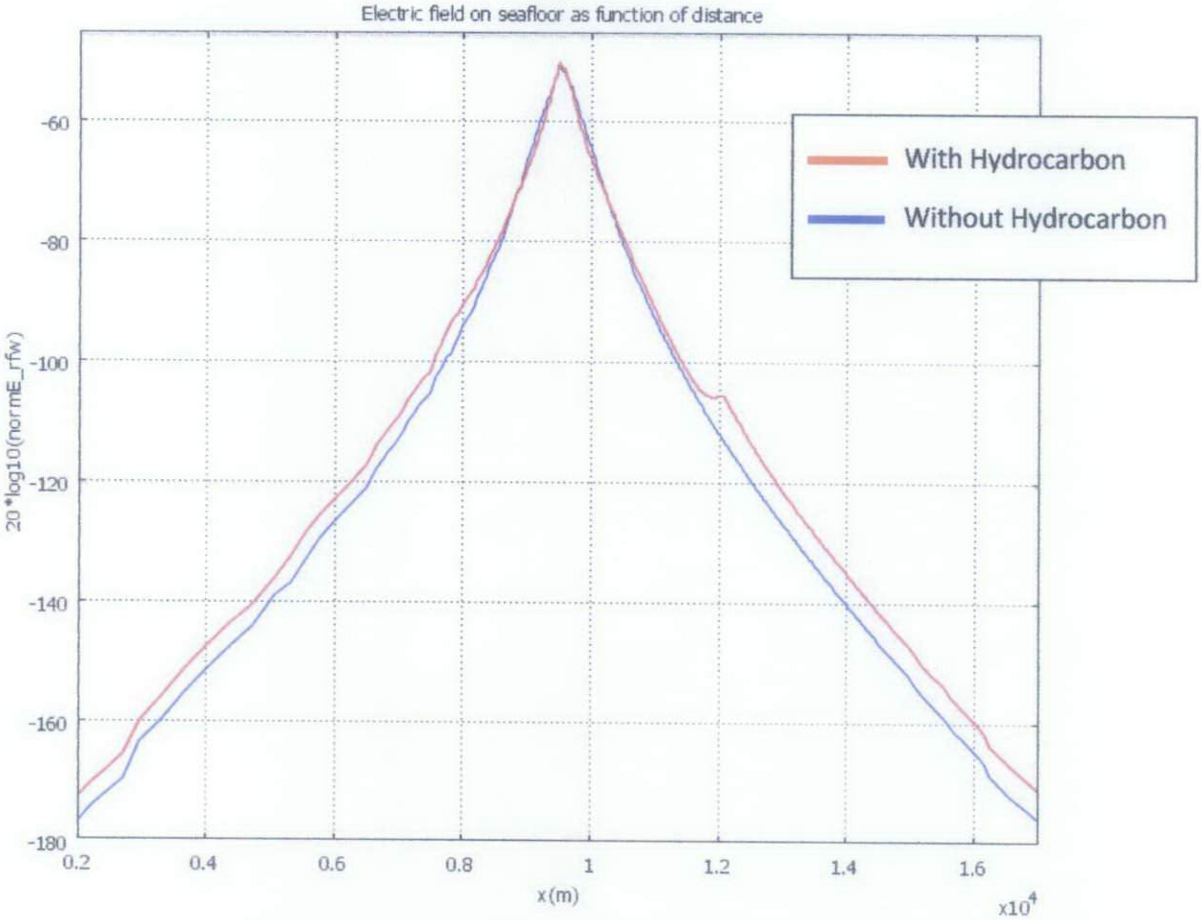

Figure 27: Graph for electric field magnitude on sea floor as function of distance

Discussion:

Result from figure 27 show the magnitude of receives electric field (E-Field) from model with hydrocarbon and without hydrocarbon. Magnitude of E-field from model with hydrocarbon is higher than the Magnitude of E-field from model without hydrocarbon. The differences can be observed at both tails of the graph, which is at distance 2000m - 9000m and at distance 11000m - 17000m.

4.1.2 Hydrocarbon is at coordinate: x= 2000, y= 2500, z= 1250

As in figure 28 the hydrocarbon was in a shape of a rectangular box and it is located 4000m under transmitter which could be seen on the left side of the SBL model.

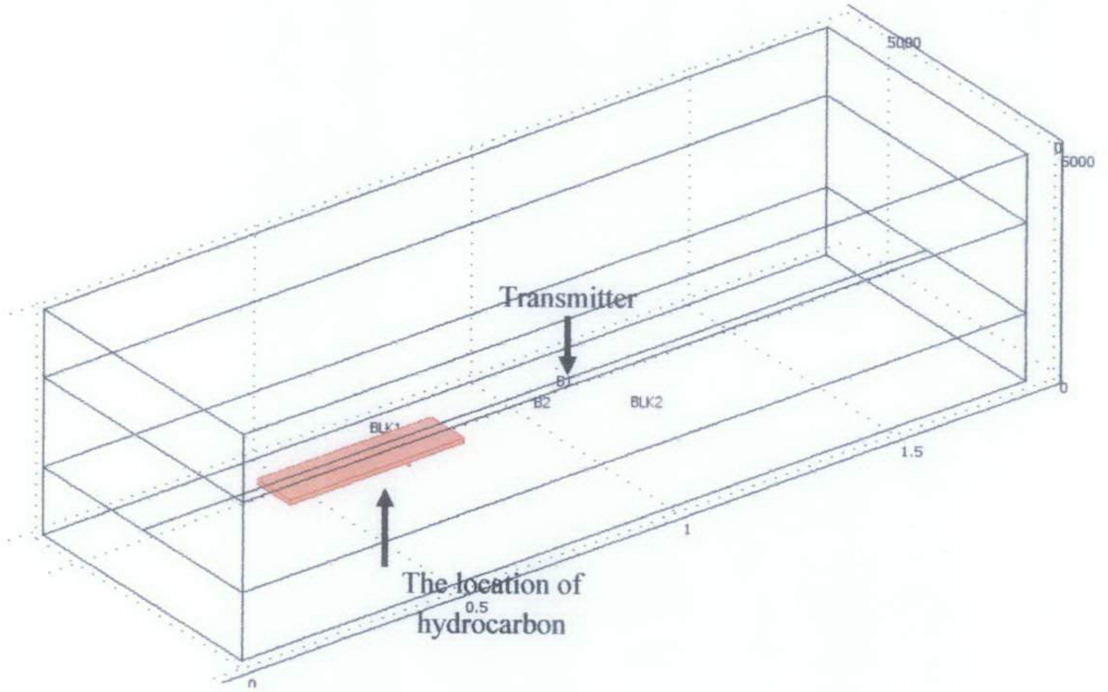

Figure 28: Location of hydrocarbon

Meshing had been done on the geometry to get the number of mesh elements. From figure 29, it shows the SBL model with hydrocarbon and area that has large number of mesh element is where the hydrocarbon was located

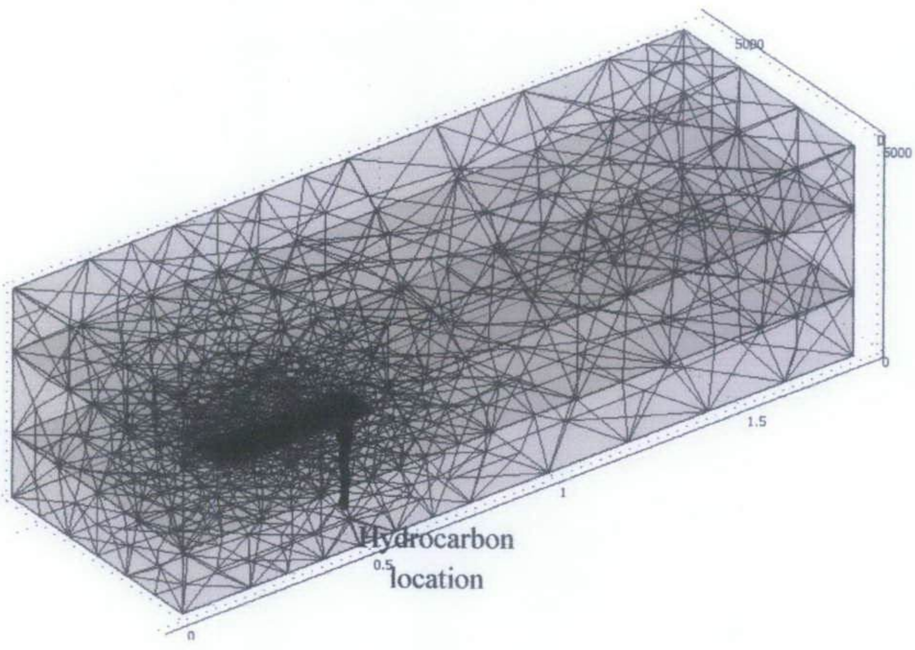

Figure 29: Mesh geometry of the seabed logging

Figure 30 shows the guiding effect of the hydrocarbon layer where as red color in the middle of the model shows the area that have the highest total energy density.

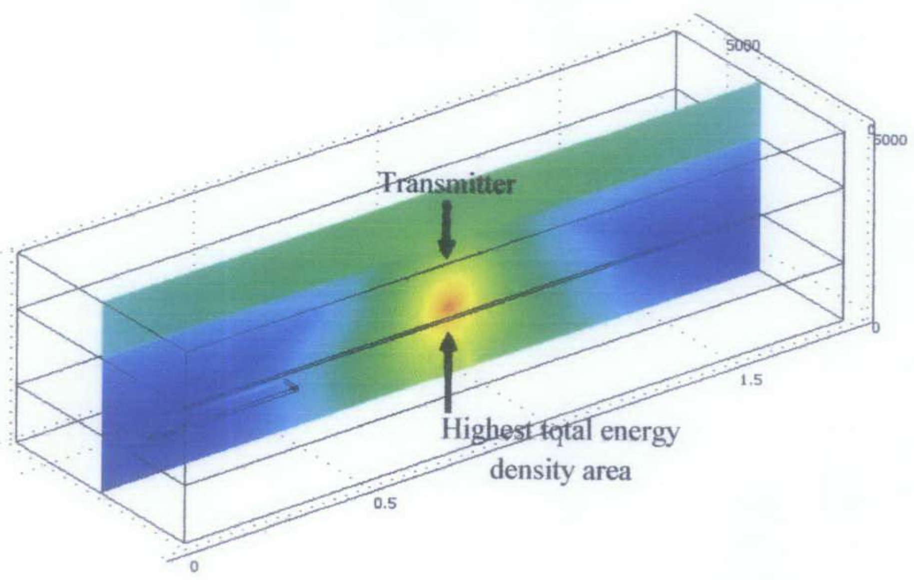

Figure 30: Total energy density on linear scale

Result:

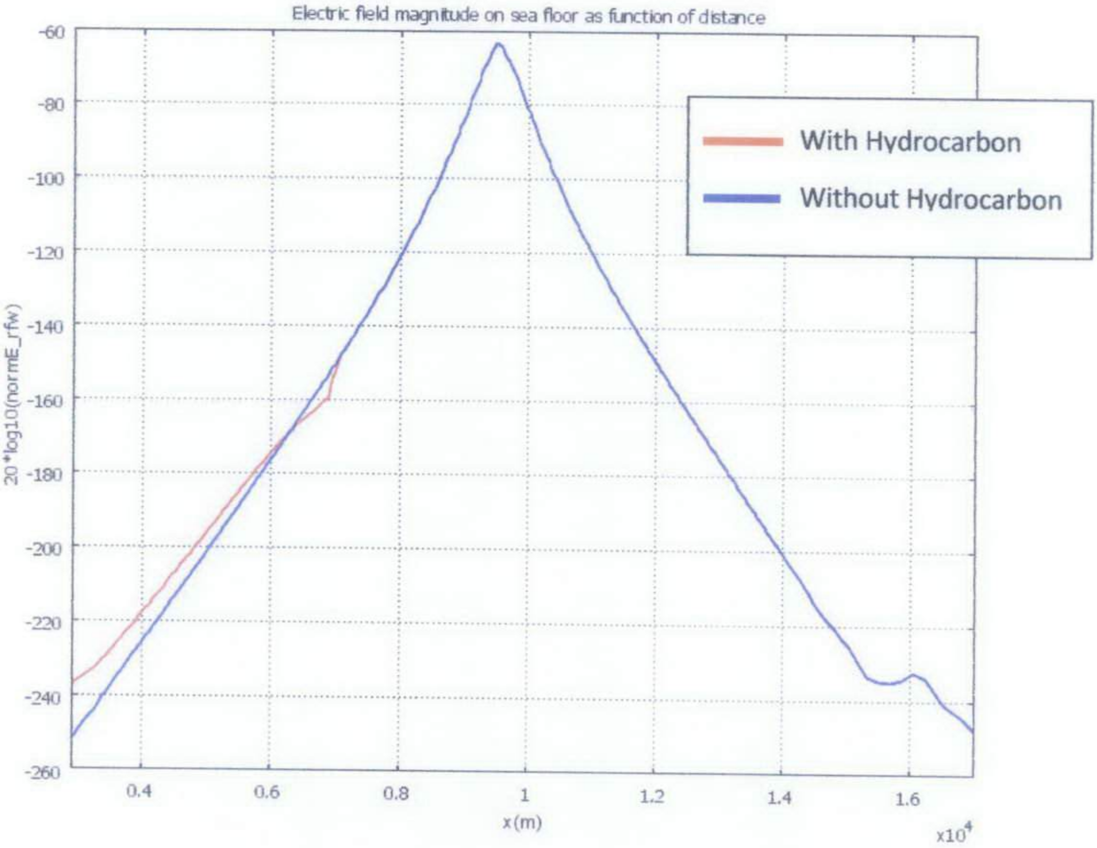

Figure 31: Graph for electric field magnitude on sea floor as function of distance

Discussion:

Result from figure 31 show the magnitude of received electric field (E-Field) from model with hydrocarbon and without hydrocarbon. Magnitude of E-field from model with hydrocarbon is higher than the Magnitude of E-field from model without hydrocarbon. The differences can be observed from one side of the graph which is from distance 4000m until 6000m. This is due to location of the hydrocarbon is at the distance of 4000m before the transmitter which is on the left of the model.

4.1.3 Hydrocarbon is at coordinate: x= 13150, y= 2500, z= 1250

As in figure 32 the hydrocarbon was in a shape of a rectangular box and it is located under transmitter which could be seen on the left side of the SBL model.

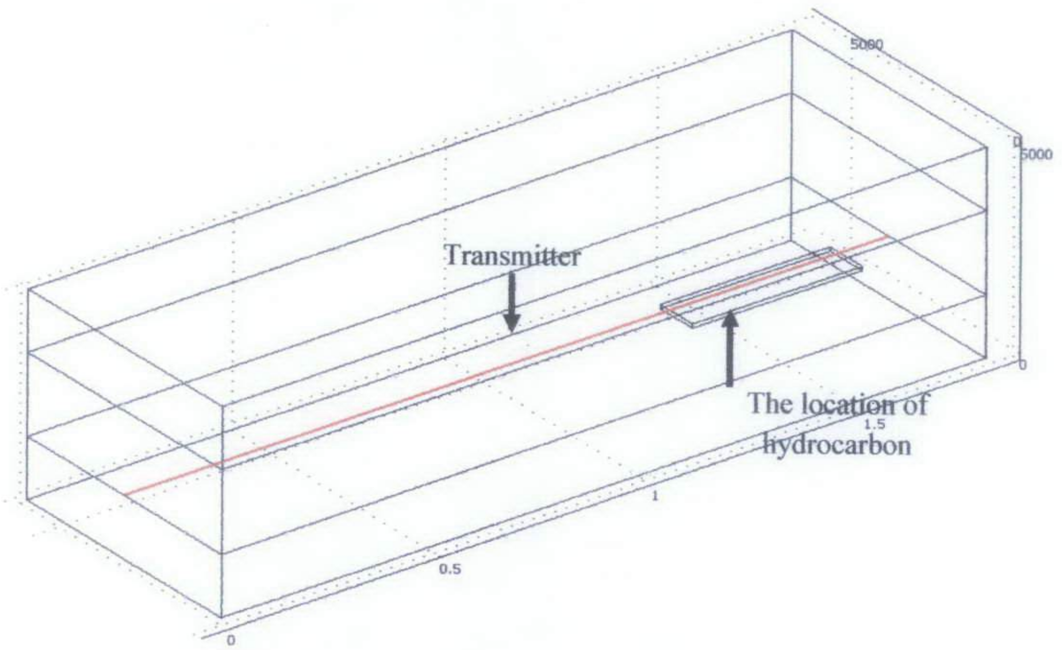

Figure 32: Location of hydrocarbon

Meshing had been done on the geometry to get the number of mesh elements. From figure 33, it shows the SBL model with hydrocarbon and area that has large number of mesh element is where the hydrocarbon was located

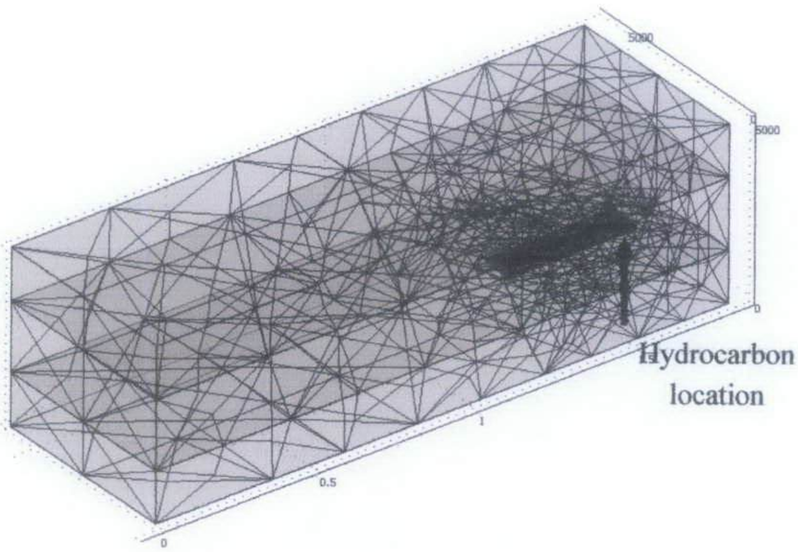

Figure 33: Mesh geometry of the seabed logging

Figure 34 shows the guiding effect of the hydrocarbon layer where as red color in the middle of the model shows the area that have the highest total energy density.

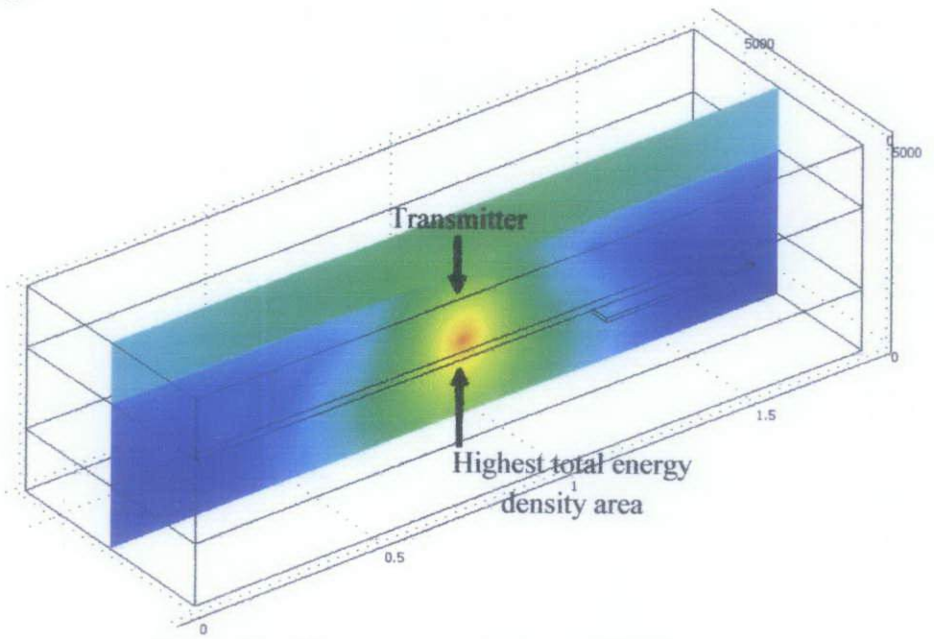

Figure 34: Total energy density on linear scale

Result:

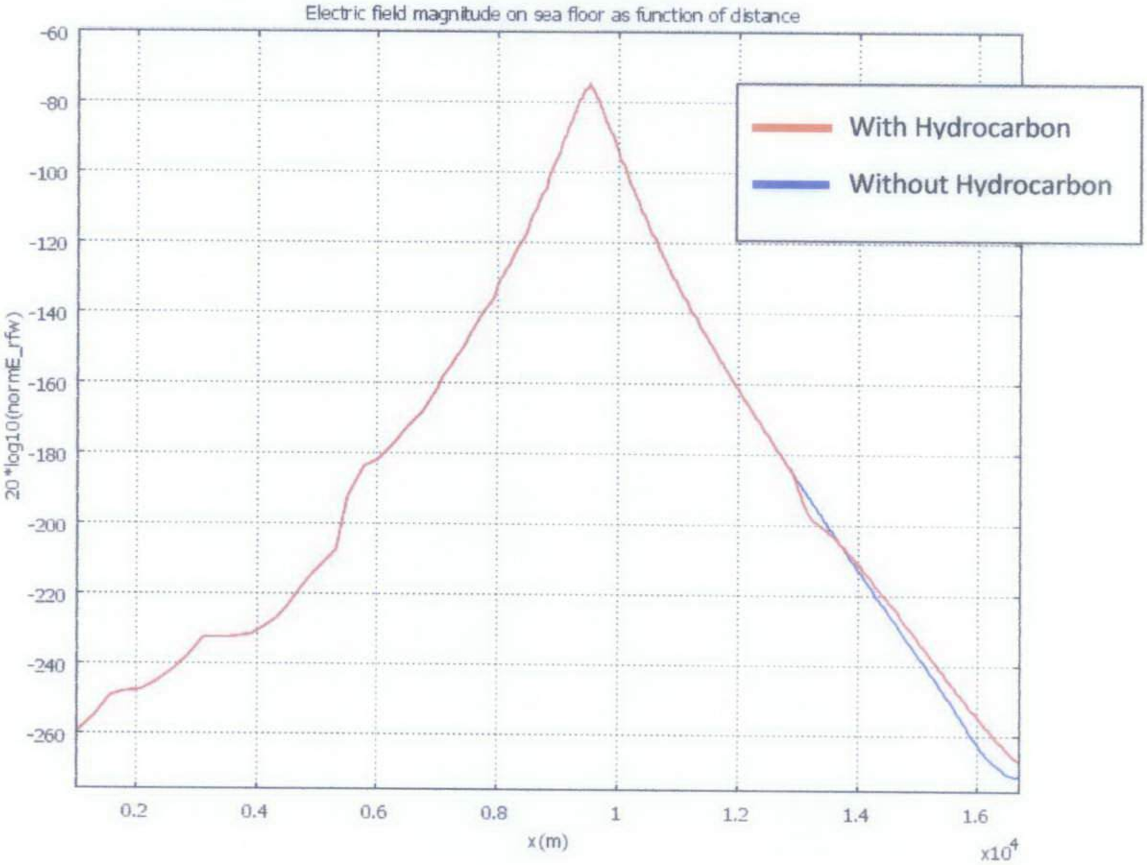

Figure 35: Graph for electric field magnitude on sea floor as function of distance

Discussion:

Result from figure 35 show the magnitude of received electric field (E-Field) from model with hydrocarbon and without hydrocarbon. Magnitude of E-field from model with hydrocarbon is higher than the Magnitude of E-field from model without hydrocarbon. The differences can be observed from one side of the graph which is from distance 14000m - 17000m. This is due to location of the hydrocarbon is at the distance of 4000m after the transmitter which is on the right of the model.

4.2 Varying the Transmitter Frequency

As stated in 3.5.2, the transmitter frequency variations will only vary frequency and other parameters are fix. Hence, seabed model in figure 36 shows that the hydrocarbon location is fix.

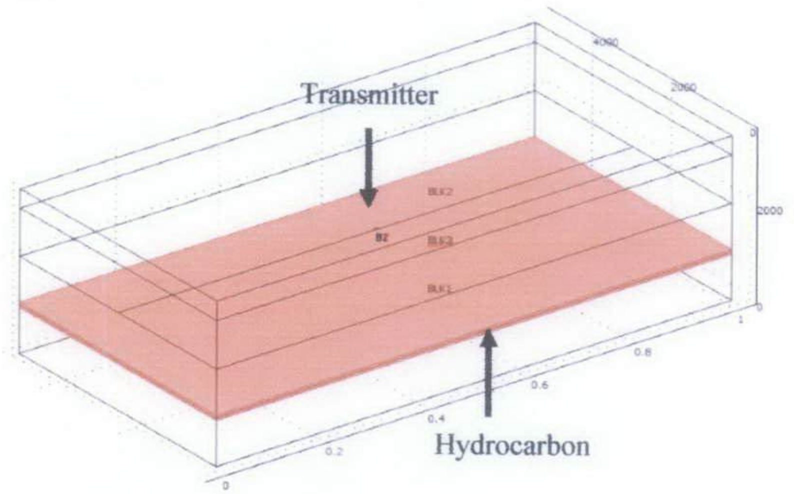

Figure 36: Seabed Model with fix hydrocarbon position

Meshing had been done on the geometry to get the number of mesh elements. From figure 37, it shows the SBL model with hydrocarbon and area that has large number of mesh element is where the hydrocarbon was located

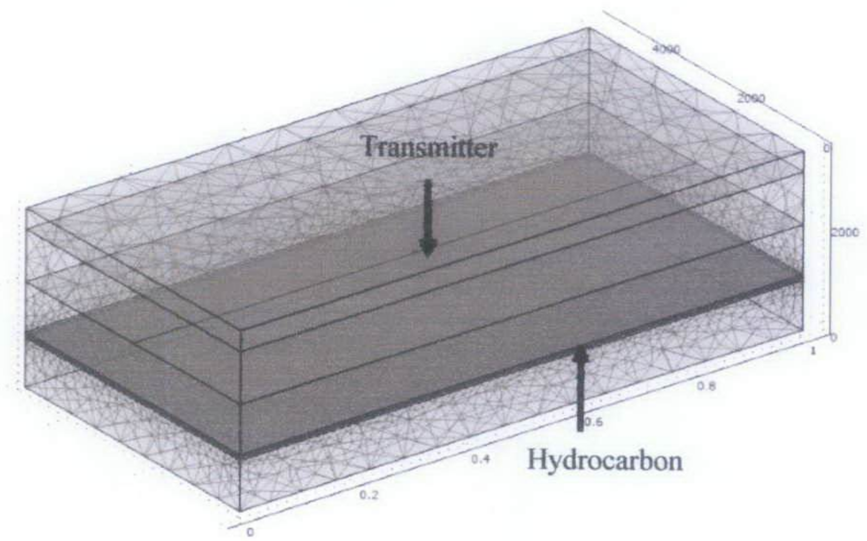

Figure 37: Mesh geometry of the seabed logging

4.2.1 Transmitter with frequency of 0.1 Hz was used in the set up

Result figure 38 shows the highest total energy density area for SBL model with transmitter frequency of 0.1 Hz. Wearers, in figure 39 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

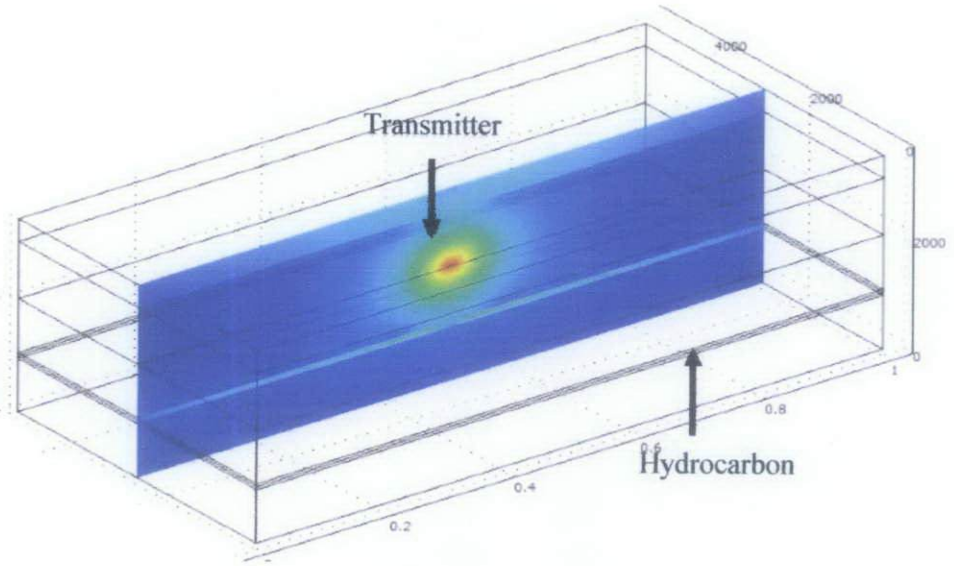

Figure 38: Total energy density on linear scale

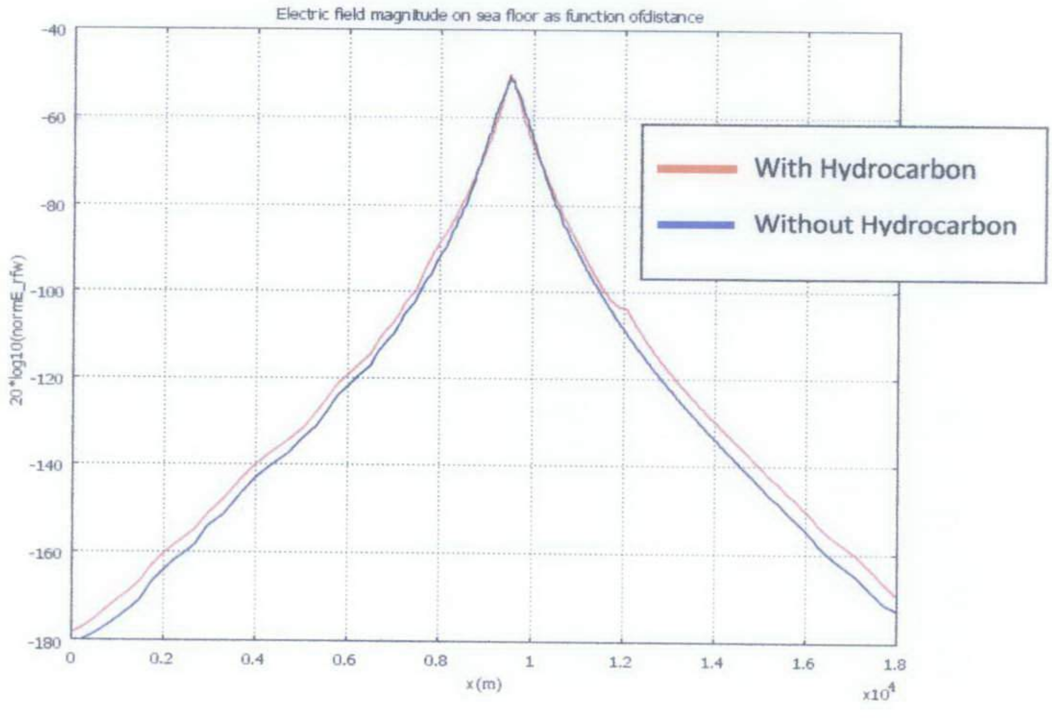

Figure 39: Graph for electric field magnitude on sea floor as function of distance

4.2.2 Transmitter with frequency of 0.25 Hz was used in the set up

Result figure 40 shows the highest total energy density area for SBL model with transmitter frequency of 0.25 Hz. Wearers, in figure 41 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

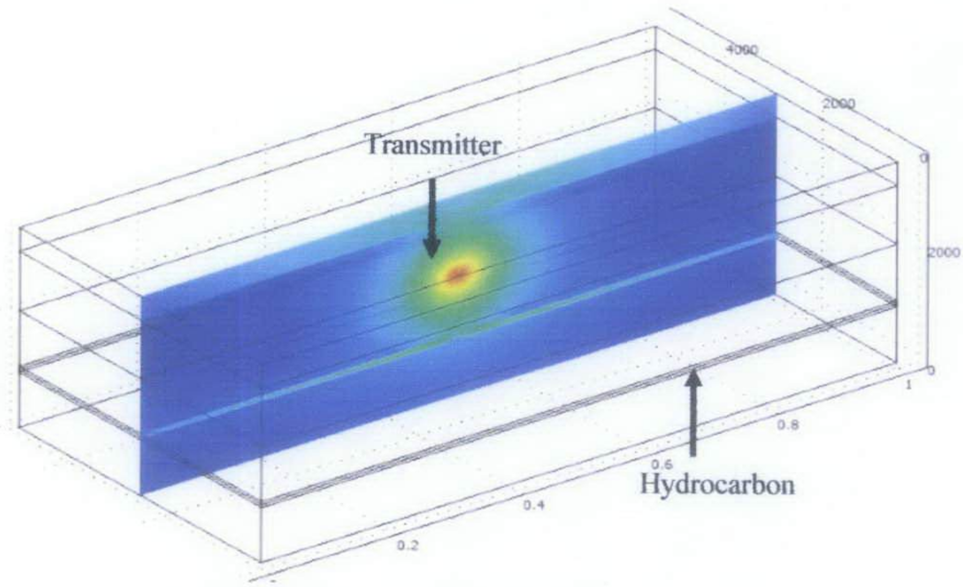

Figure 40: Total energy density on linear scale

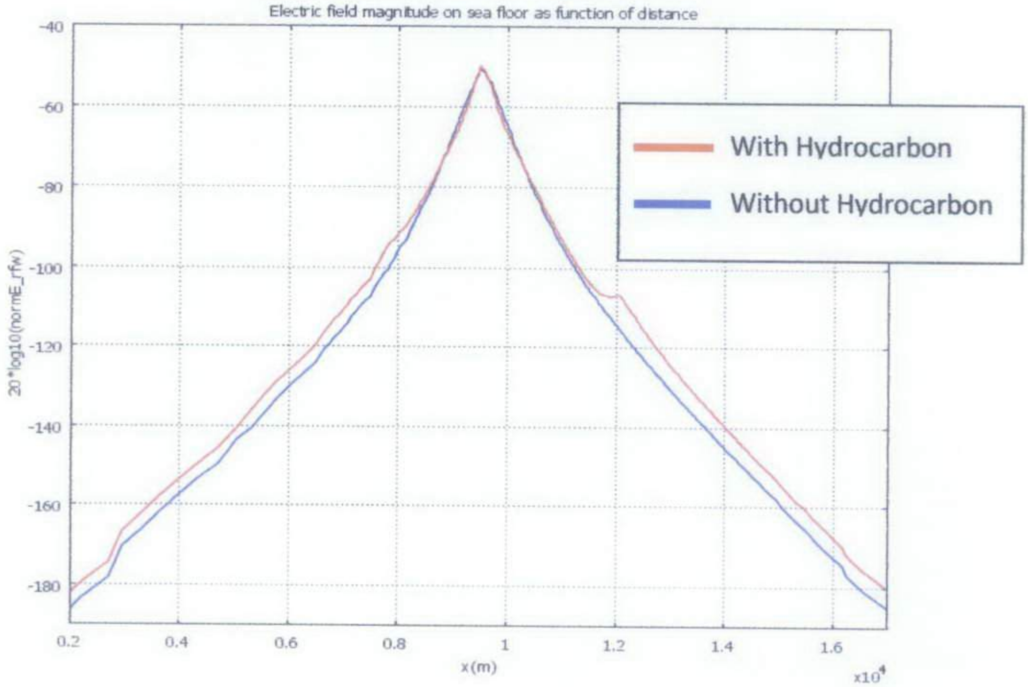

Figure 41: Graph for electric field magnitude on sea floor as function of distance

4.2.3 Transmitter with frequency of 0.5 Hz was used in the set up

Result figure 42 shows the highest total energy density area for SBL model with transmitter frequency of 0.5 Hz. Wearers, in figure 43 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

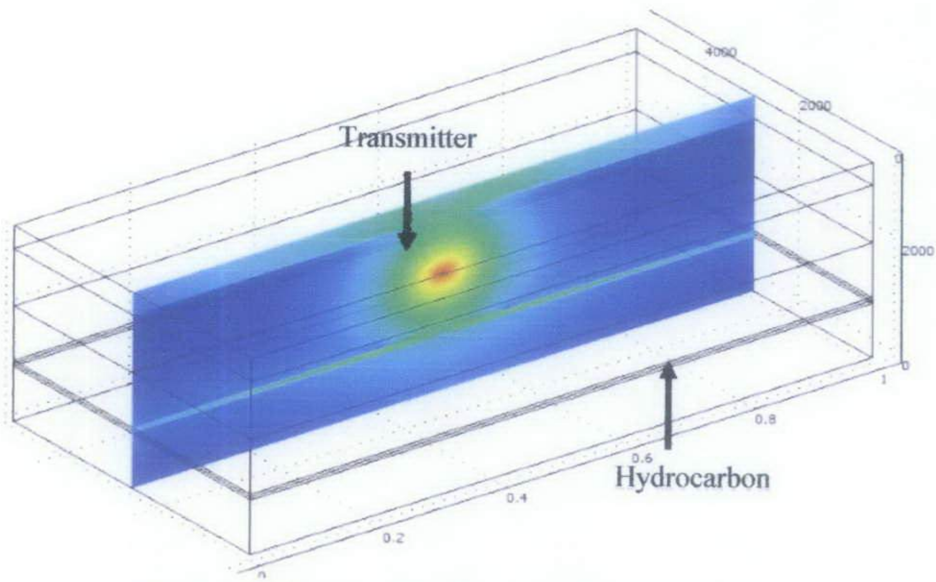

Figure 42: Total energy density on linear scale

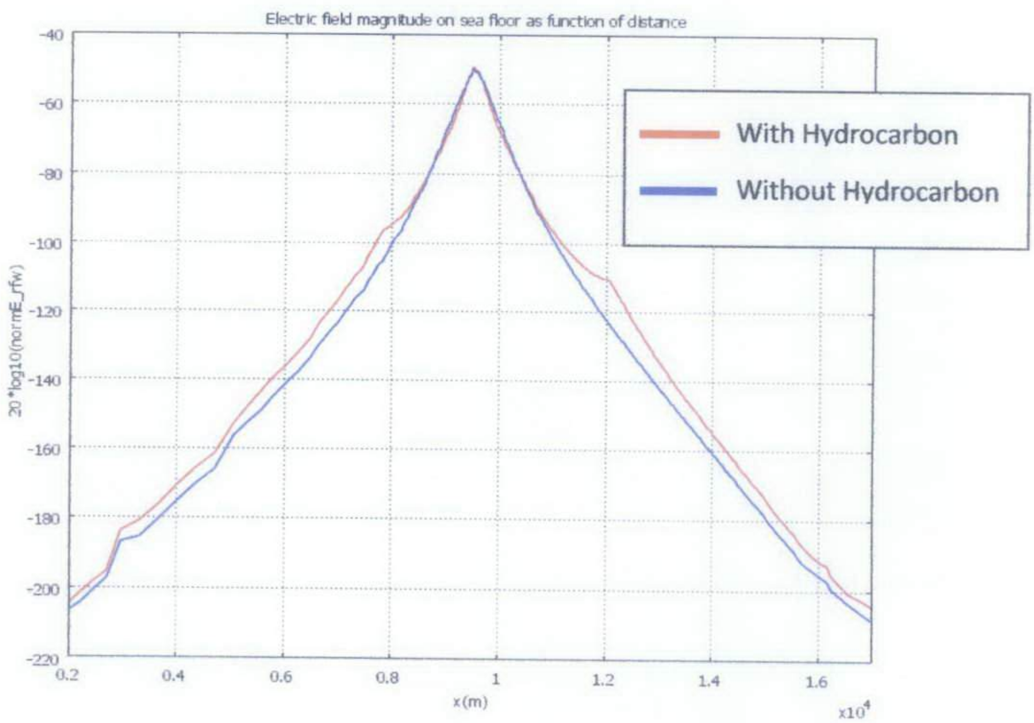

Figure 43: Graph for electric field magnitude on sea floor as function of distance

4.2.4 Transmitter with frequency of 0.75 Hz was used in the set up

Result figure 44 shows the highest total energy density area for SBL model with transmitter frequency of 0.75 Hz. Wearers, in figure 45 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

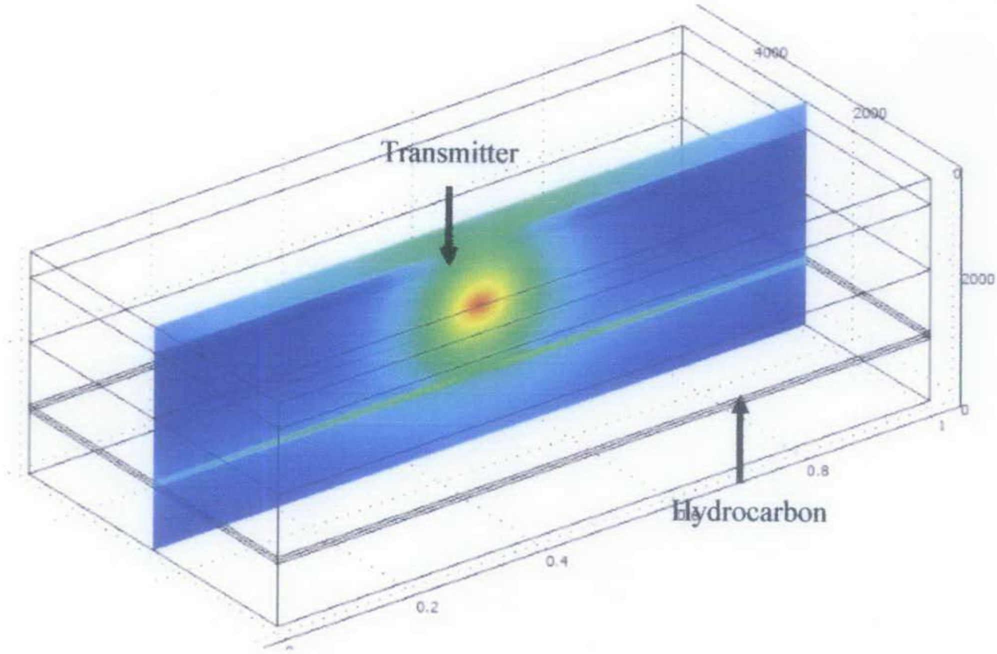

Figure 44: Total energy density on linear scale

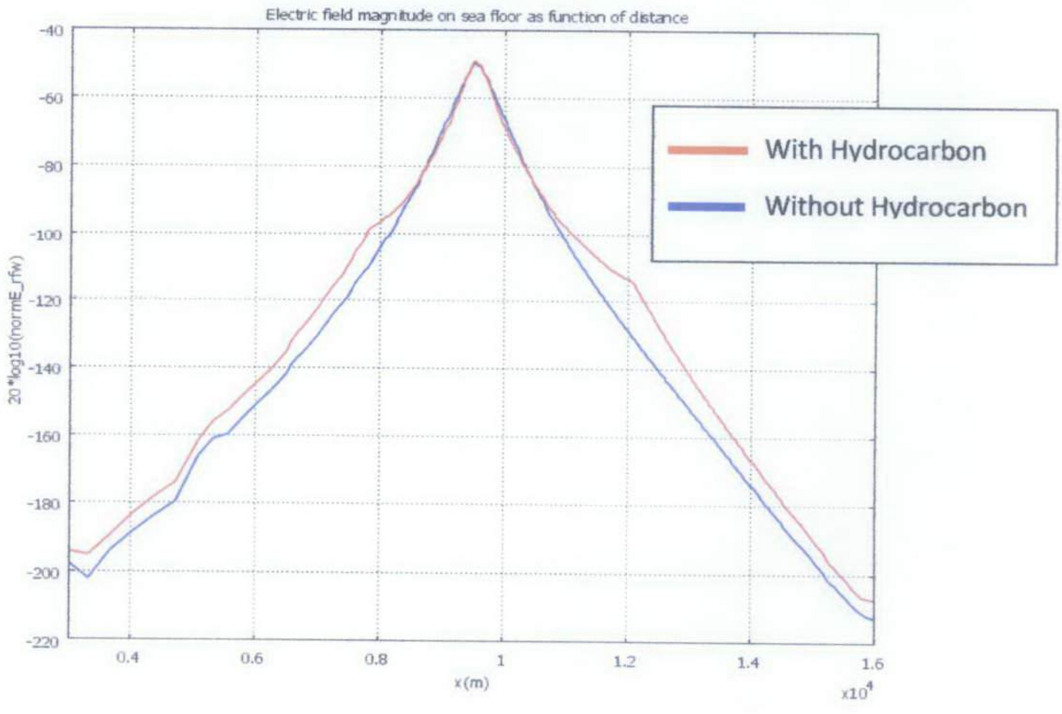

Figure 45: Graph for electric field magnitude on sea floor as function of distance

4.2.5 Transmitter with frequency of 1.0 Hz was used in the set up

Result figure 46 shows the highest total energy density area for SBL model with transmitter frequency of 1.0 Hz. Wearers, in figure 47 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

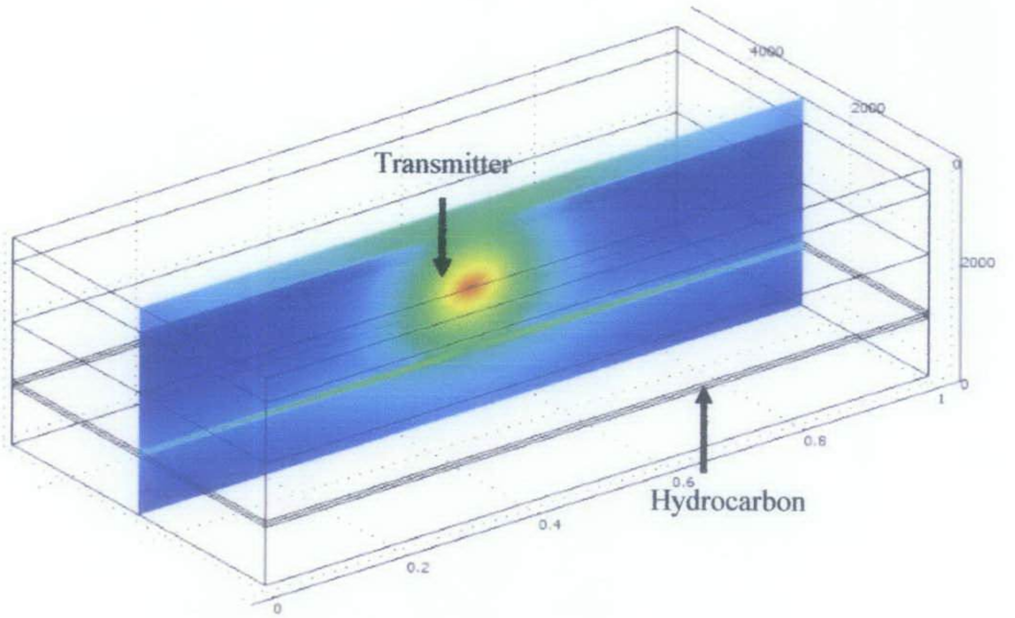

Figure 46: Total energy density on linear scale

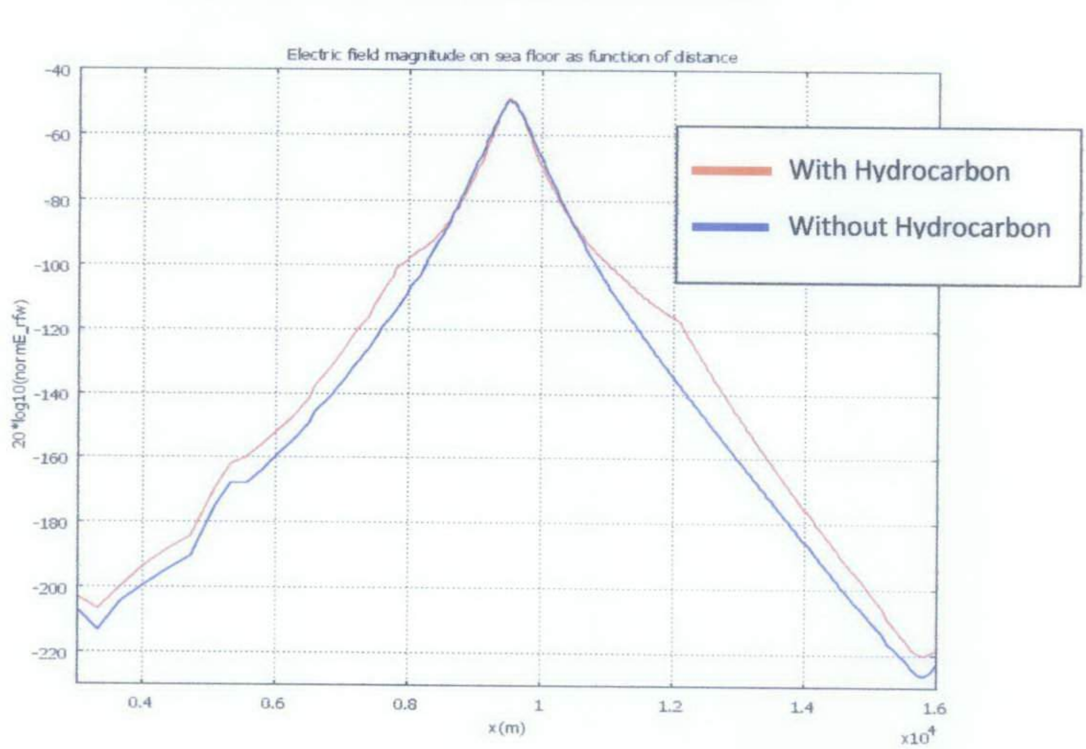

Figure 47: Graph for electric field magnitude on sea floor as function of distance

4.2.6 Transmitter with frequency of: 0.1Hz, 0.25Hz, 0.5Hz, 0.75Hz, 1.0Hz

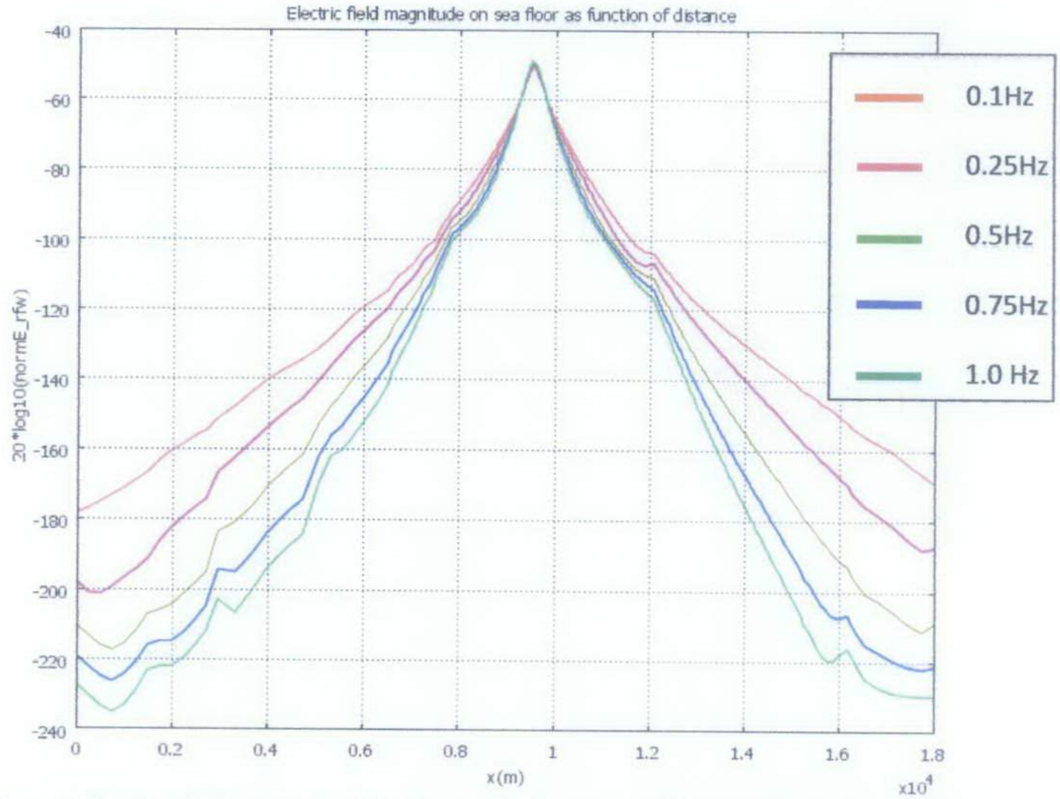

Figure 48: Graph for electric field magnitude on sea floor as function of distance

Discussion:

From figure 48 it is shown that model of SBL with 0.1Hz of frequency receive the highest magnitude of E-field compared to model with 0.25Hz, 0.5Hz, 0.75Hz, and 1.0Hz of frequency. Therefore, the smaller the frequency the higher the magnitude of the electric field.

4.3 Varying the Overburden Thickness

Then continued with varying the overburden thickness to 1000m, 1500m, 2000m, 2500m, 3000m, 3500m, and 4000m. From figure 49, it shows the guiding effect of SBL model with overburden thickness of 1000m.

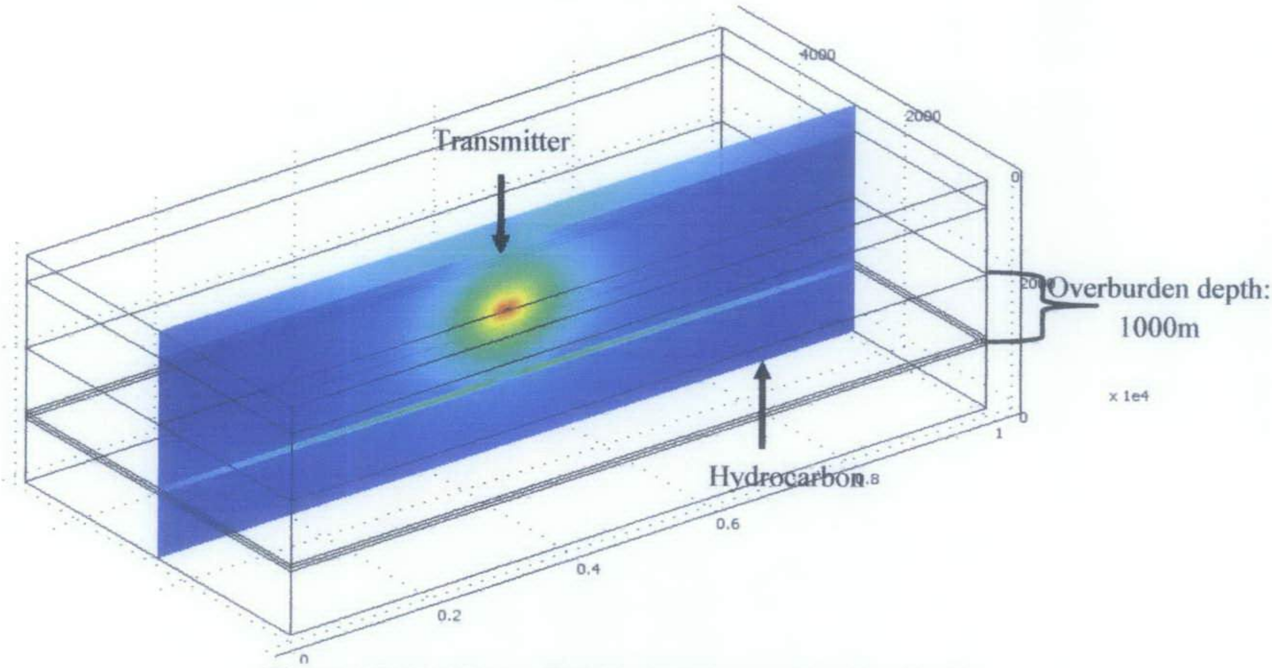

Figure 49: Guiding effect for 1000m overburden depth

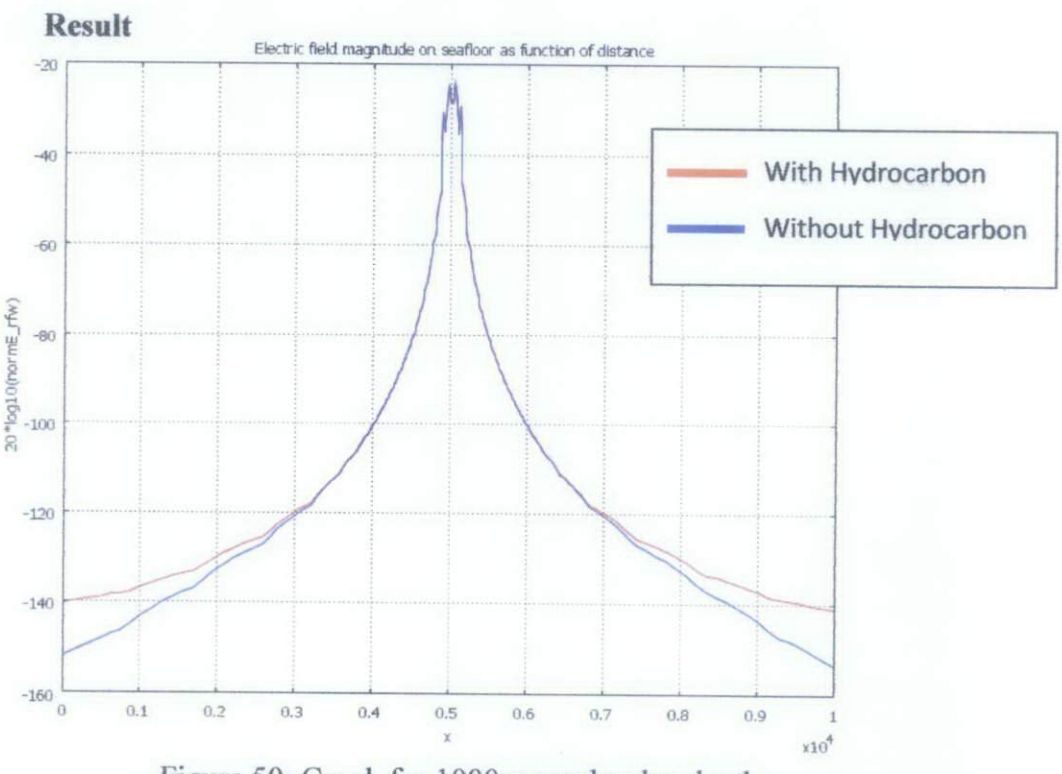

Figure 50: Graph for 1000m overburden depth

From figure 51, it shows the guiding effect of SBL model with overburden thickness of 1500m.

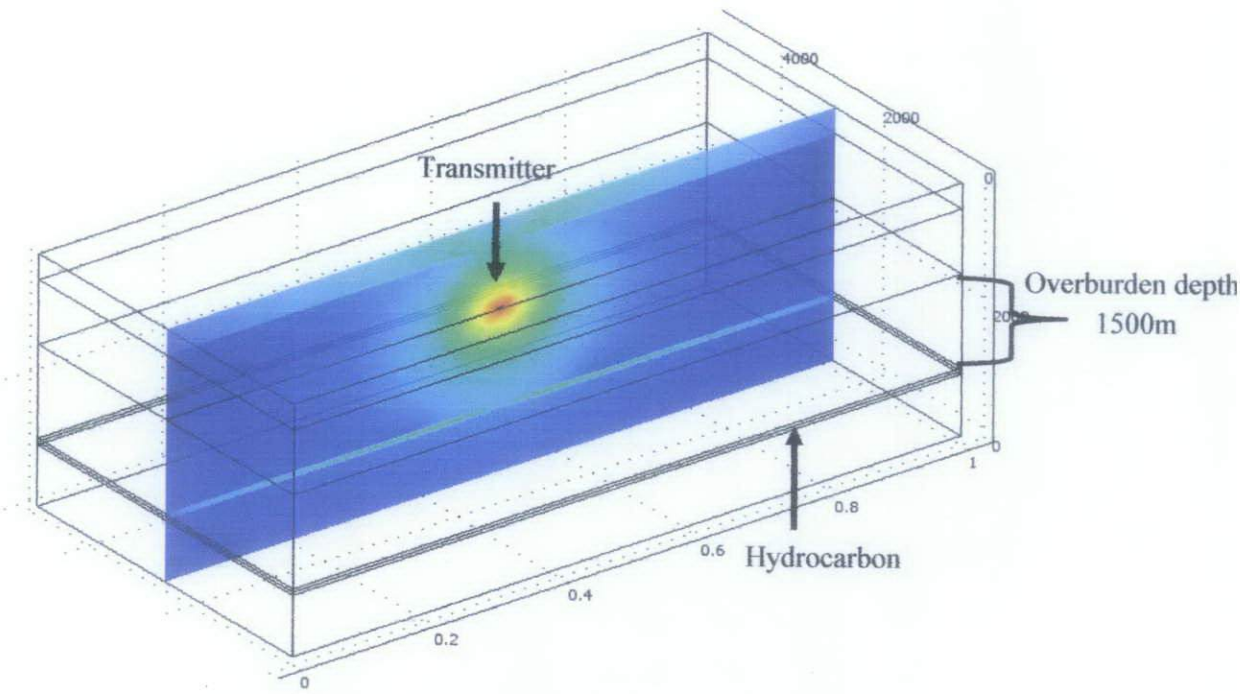

Figure 51: Guiding effect for 1500m overburden depth

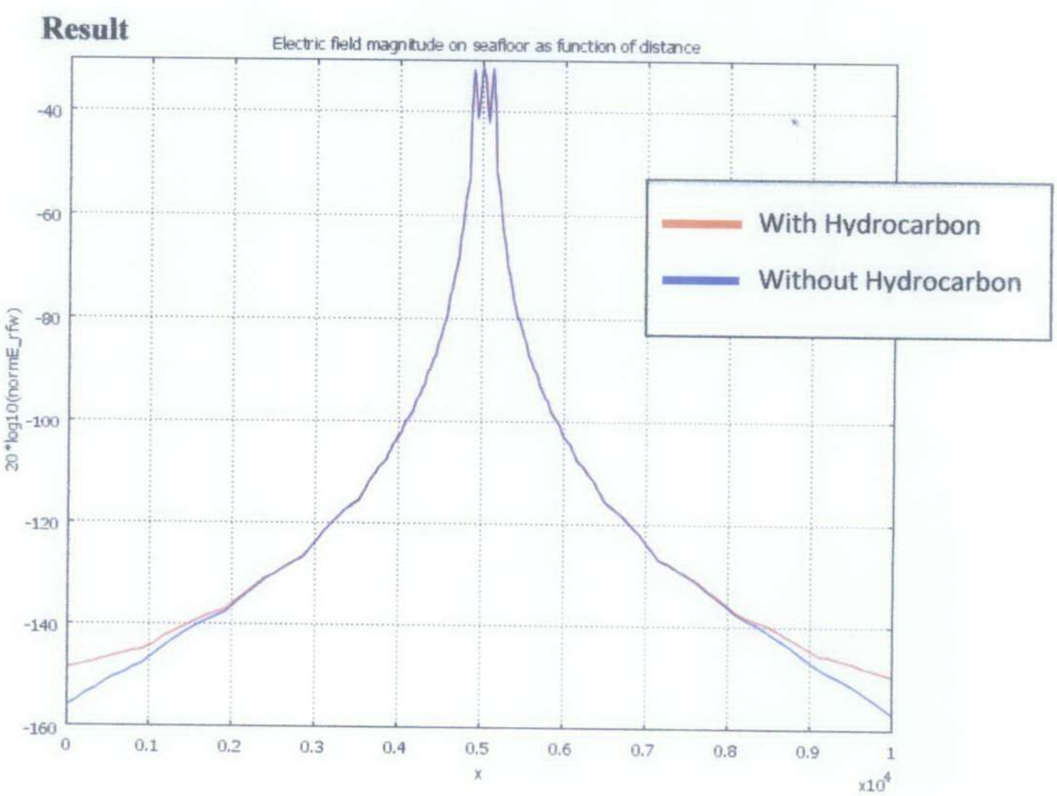

Figure 52: Graph for 1500m overburden depth

From figure 53, it shows the guiding effect of SBL model with overburden depth of 2000m.

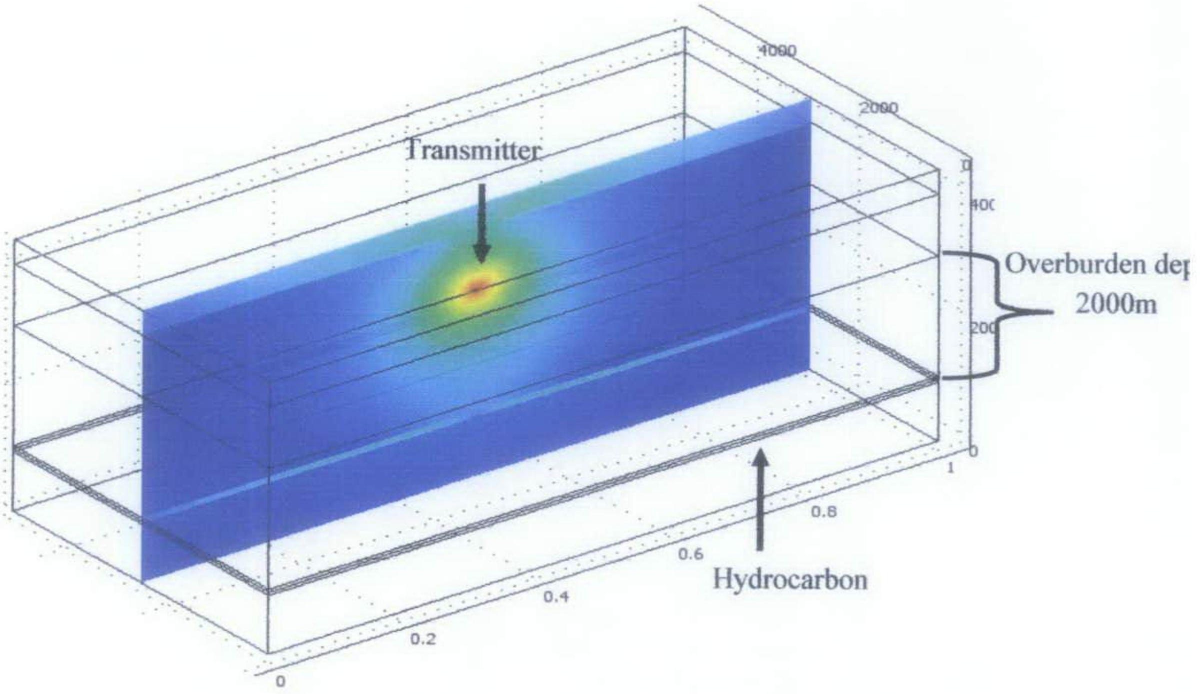

Figure 53: Guiding effect for 2000m overburden depth

Result

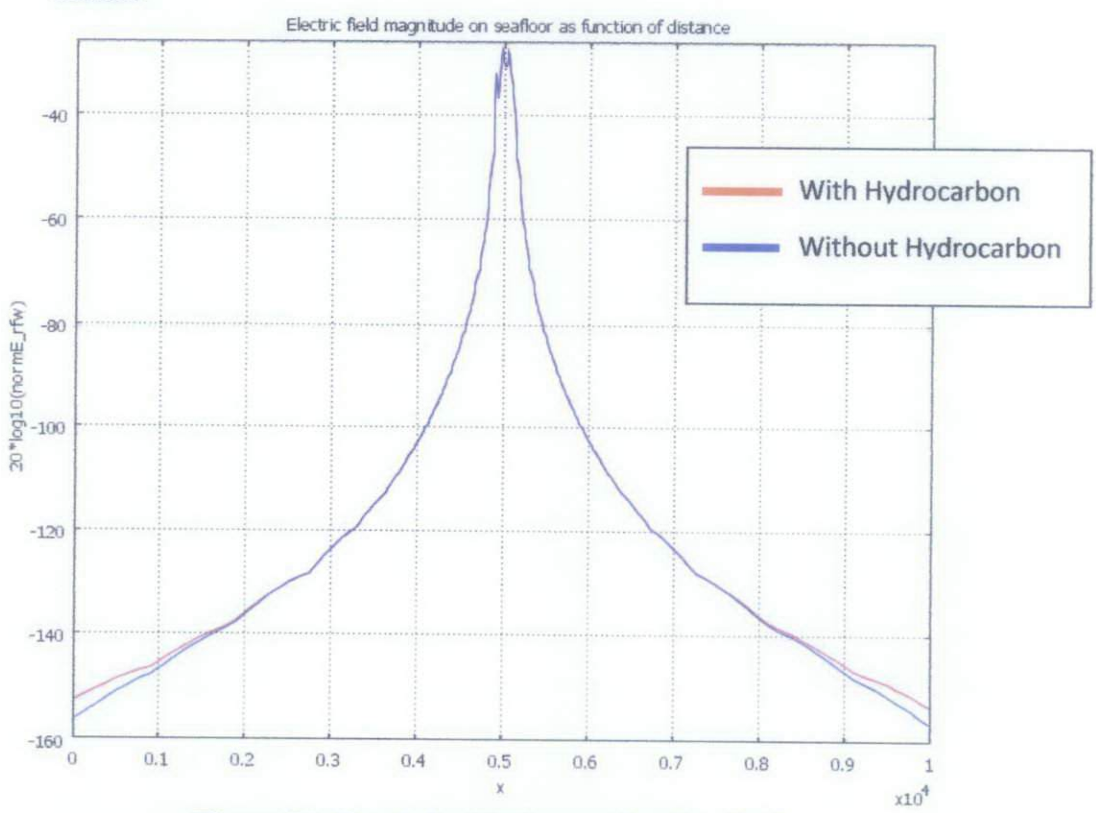

Figure 54: Graph for 2000m overburden depth

From figure 55, it shows the guiding effect of SBL model with overburden depth of 2500m.

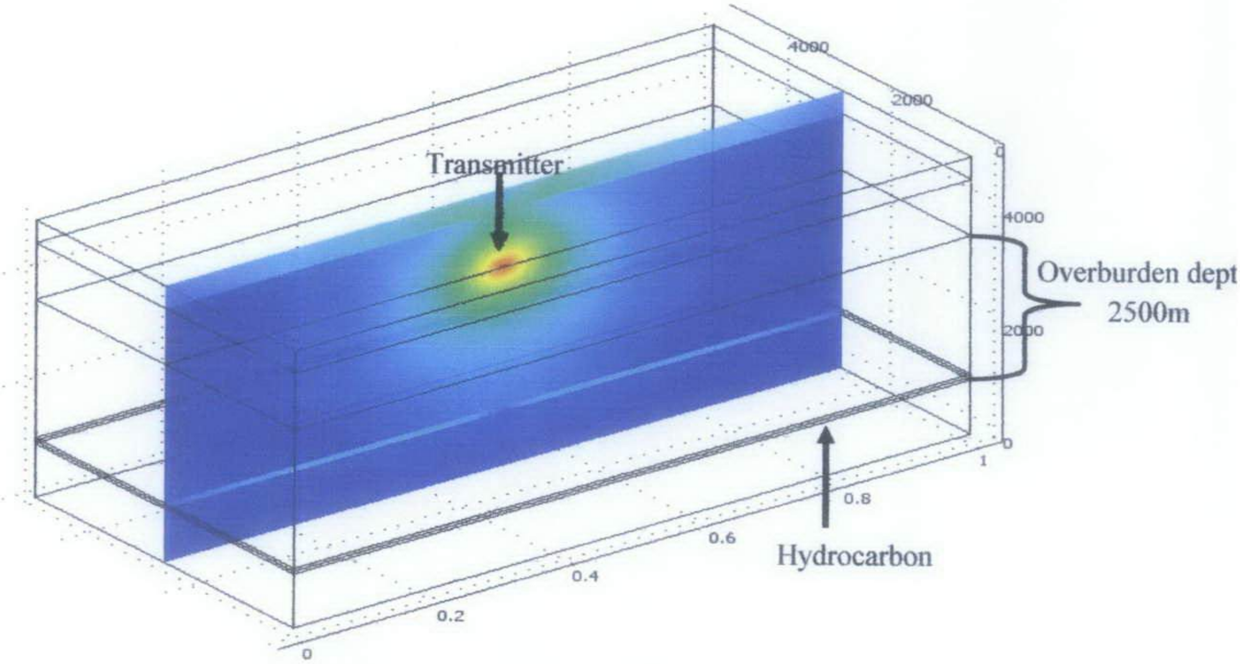

Figure 55: Guiding effect for 2500m overburden depth

Result

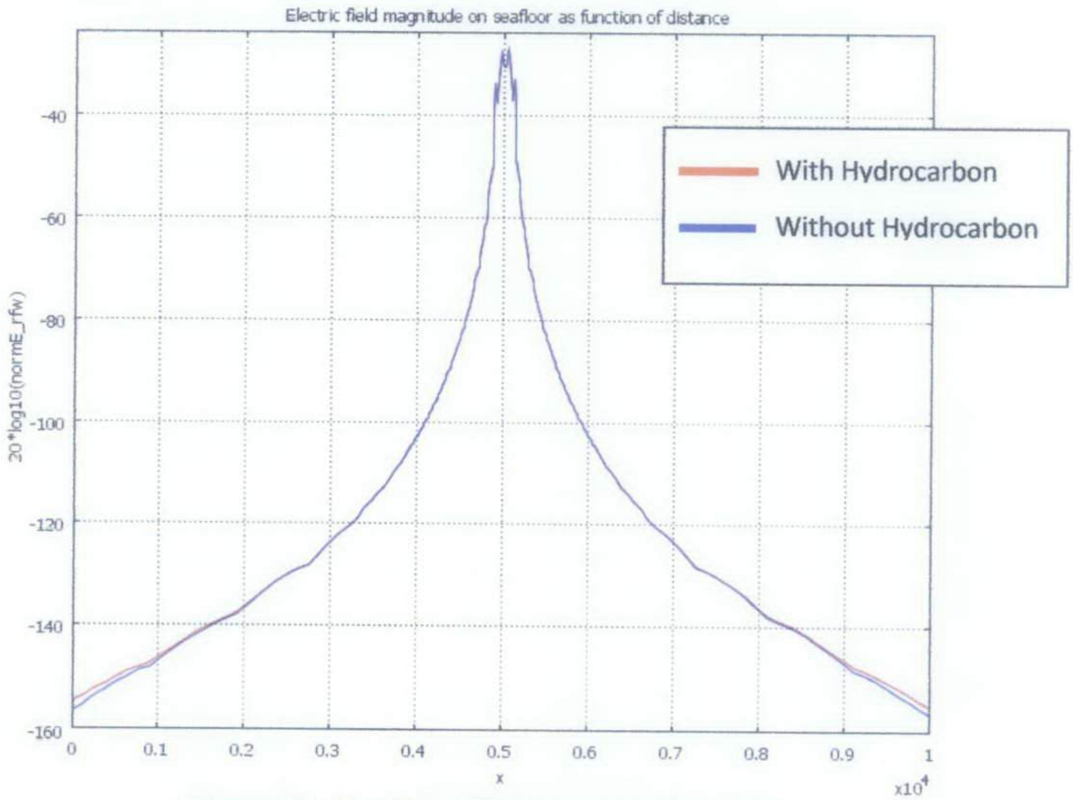

Figure 56: Graph for 2500m overburden depth

From figure 57, it shows the guiding effect of SBL model with overburden depth of 3000m.

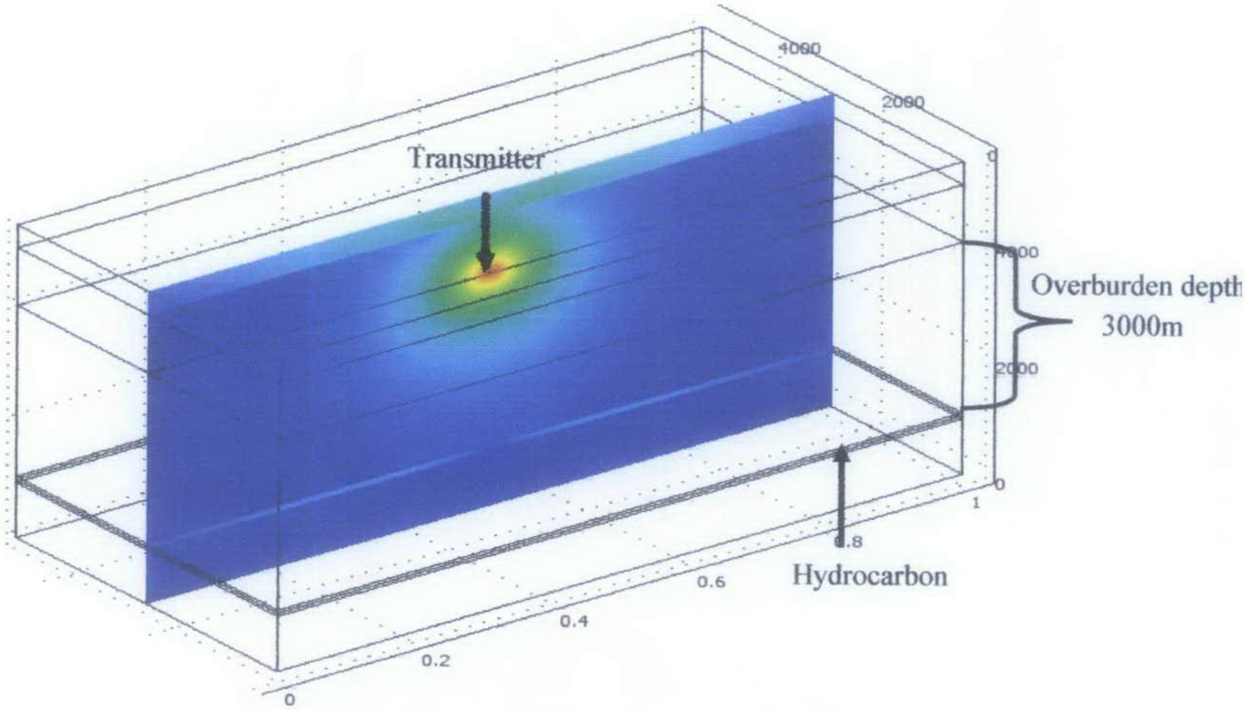

Figure 57: Guiding effect for 3000m overburden depth

Result

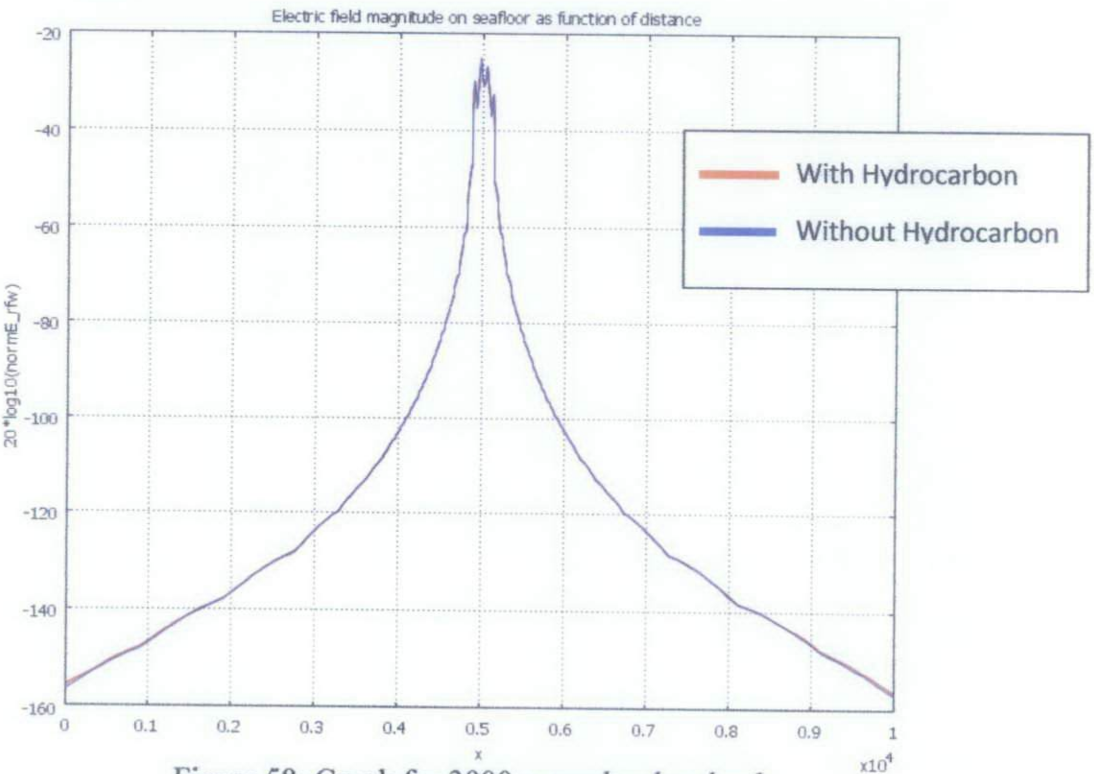

Figure 58: Graph for 3000m overburden depth

Discussion:

When thickness of overburden reaches 3000 m there is no different shown on the graph between model with hydrocarbon and without hydrocarbon. Thus, it is shown that the reflected EM waves cannot reach receiver after the thickness of overburden reach 3000 m. The deeper the depth of the hydrocarbon the smaller the effect of the E-field at the receiver.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In a nutshell, authors conclude that this project will bring a lot of benefit to the future and can be applied to a multinational oil and gas company. By modeling 3D simulator of EM waves for seabed logging application using COMSOL hopefully it can interpret data from the receiver and give an accurate result for user easy understanding. This simulator can also improve the difficulty to predict the existing of hydrocarbon underneath the sea floor because it will show user figures of hydrocarbon layer plane, water, and sediment. Furthermore, it can also determine the effect of airwave to receiver when different variables are varied.

5.2 Recommendations

Improvement on developed SBL simulator can be done by including more inputs parameter option that considers bathymetry effect, temperature, pressure, and all sizes of hydrocarbon reservoir.

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APPENDIX 1: GANTT CHART FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Selection and Confirmation of Project Title								MID SEMESTER BREAK								STUDY WEEK		EXAM WEEK		
2	Gathering information on Seabed Logging																				
3	Submission of Preliminary Report																				
4	Study on COMSOL architecture and Seabed Logging Model																				
5	Submission of Progress Report																				
6	Design modelling and simulation in COMSOL																				
7	Seminar																				
8	Finalize project work																				
9	Submission of Interim Draft Report																				
10	Submission of Interim Final Report																				
11	Oral Presentation																				

APPENDIX 1: GANTT CHART FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Seabed Logging model development and modification work																				
2	Submission of Progress Report							M													
								I													
3	Project work continues							D													
																S	E				
4	Testing and Validation work							S								T	X				
								E								U	A				
5	Pre-EDX							M								D	M				
								E								Y					
6	Finalize results and findings							S													
								T								W	W				
7	Submission of Draft Report							E								E	E				
								R								E	E				
8	Submission of Final Report and Technical paper.															K	K				
								B													
9	Oral Presentation							R													
								E													
								A													
								K													